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A LUMPED-PARAMETER INTERIOR BALLISTIC COMPUTER CODE USING THE TTCP MODEL

FREDERICK W. ROBBINS
TIMOTHY S. RAAB

NOVEMBER 1988

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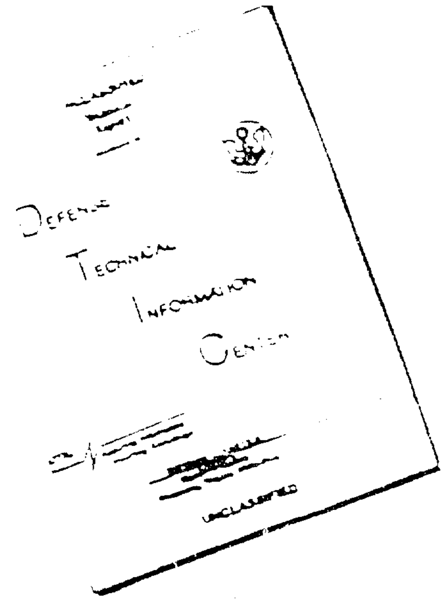

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ERRATA SHEET FOR BRL-MR-3710

A LUMPED-PARAMETER INTERIOR BALLISTIC COMPUTER CODE USING THE TTCP MODEL

PAGE	DESCRIPTION
10	'Nordheim heat transfer coefficient' should be 'Nordheim friction factor'
10	In equation 7.19 remove dt
13	The units for h should be watt/m^2-K
14	'resistive force to projectile motion' should be 'resistive force to recoil motion' in definition of RP
14	'Nordheim heat transfer coefficient' should be 'Nordheim friction factor' in definition of lambda
28	Units for free convective heat transfer coefficient should be W/cm^2-K

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IBRGA is a simple FORTRAN code for making computer simulations of the interior ballistic performance of guns. It can be run on computers as small as an IBM PC. It is based on the lumped-parameter mathematical model of interior ballistics recently adopted by the The Technical Cooperation Program (TTCP), and therefore it permits validation of that model. While the TTCP model is limited to a Lagrange pressure gradient equation, IBRGA also permits using a gradient equation which takes into account the chambrage of the gun. Calculations with IBRGA agree with the results of gun firings, which show higher muzzle velocities for guns with chambrage than for guns with chambers of constant diameter. IBRGA is used to show gun optimizations performed with Lagrange gradients for guns without chambrage lead to nearly-optimal propellant grain dimensions for use in guns with chambrage.

This report documents IBRGA thoroughly. It includes comparisons with IBHVG2, a complete FORTRAN listing of the IBRGA code, and sample inputs and outputs.

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I. INTRODUCTION

Recently, The Technical Cooperation Program (TTCP), WTP-4 (Propulsion Technology), Key Technical Area 10 (KTA-10) adopted a lumped-parameter interior ballistics model. The model is well documented in the report of the activities of the KTA.[1] IBRGA was written in order to test that model, to compare its predictions with those of other established models, and to provide a relatively simple interior ballistics model for other uses by the community. IBRGA is a FORTRAN encoding of the TTCP model. It has been compiled and run on computers as small as an IBM PC and as large as a CRAY-2. This report documents IBRGA quite thoroughly, including comparisons with IBHVG2, a complete FORTRAN listing of the IBRGA code, and sample inputs and outputs. A machine-readable copy of the code, complete with sample inputs and outputs, may be obtained from the authors of this report.

II. DISCUSSION OF IBRGA

IBRGA performs all its calculations with variables expressed in metric units, specifically, meters, kilograms, and seconds. The input data units were made to conform to those of TDNOVA[2] for the sake of uniformity. Some of the required input data are therefore in centimeters, grams, and milliseconds; IBRGA converts to the basic metric units before the interior ballistic simulation begins.

There are two forms of IBRGA available, the difference between them being the method used to calculate the mass fraction of propellant burned. IBRGAS is a direct encoding of the TTCP model; it is included as Appendix A. IBRGAS uses the formula $Z_i = \left[\frac{1}{v_o}\right] \int_0^t s(t) \frac{dx}{dt}\, dt$, where Z_i is the mass fraction burned, v_o is the original volume of propellant, $s(t)$ is the instantaneous surface area and $\frac{dx}{dt}$ is the linear burning rate. IBRGAC is the other version of the code; it uses the relation $Z_i = \frac{v_t}{v_o}$, where Z_i is the mass fraction burned, v_t is the instantaneous volume of propellant burned, which is calculated from the regression of the propellant surface and the geometry of the propellant grains, and v_o is the original volume of propellant. This alternative solution technique was expected to yield the same answers but to be numerically quicker. The two versions of IBRGA are compared in Table 1. Calculated peak breech pressures, in MPa, are shown versus the chosen time step for the calculations. These comparisons were done with the Cray X-MP/48 computer, both for the long word length and the calculational speed. The run times are for the Cray X-MP/48. One can see that the codes converge to the same value, but that convergence is about a factor of 100 quicker with IBRGAC than with IBRGAS.

TABLE 1

COMPARISON OF IBRGAC AND IBRGAS

Calculated Peak Breech Pressures in MPa

Time Step (s)	IBRGAC	IBRGAS	Approx. Run Time (s)
.05	517.451	508.526	0.10
.005	517.574	516.642	0.44
.0005	517.582	517.489	3.90
.00005	517.583	517.574	37.40
.000005	517.583	517.582	373.00

Based on these findings, all subsequent calculations with IBGRA in this report used IBRGAC with a time step of 0.005 seconds.

The basic physical assumptions involved in IBRGAC are the same as those for the lumped-parameter interior ballistics code called IBHVG2[3]. Both codes can make use of the Lagrange gradient equation in addition to other gradients. To test the accuracy of IBRGAC, comparison computer runs were made with IBHVG2. Both codes used essentially the same nominal 120-mm data base and employed the Lagrange gradient equation. Results of these calculations are summarized in Table 2. The percentage difference between the results of the two codes is shown to the right. With differences between variables compared of the order of 0.01%, the agreement between the two codes is quite satisfactory.

TABLE 2

COMPARISON OF DATA BETWEEN IBRGAC AND IBHVG2

Trajectory variables	IBRGAC	IBHVG2	% difference
Maximum breech pressure(MPa)	517.574	517.588	0.003%
Maximum mean pressure(MPa)	460.047	460.060	0.003%
Maximum base pressure(MPa)	344.994	345.003	0.003%
Muzzle velocity(m/s)	1576.09	1575.95	0.009%

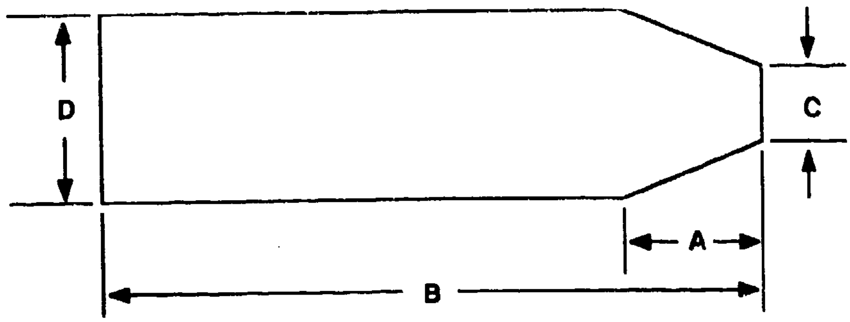
Energy variables (J)	IBRGAC	IBHVG2	% difference
Total chemical energy	48,384,300.	48,373,692.	0.022%
Energy remaining in the gas	30,765,100.	30,766,890	0.006%
Projectile kinetic energy	12,173,200.	12,164,775.	0.069%
Energy lost to gas and propellant motion	4,059,700.	4,056,875.	0.070%
Heat energy lost to convection	1,386,220.	1,385,152.	0.077%

In addition to the Lagrange pressure gradient equation, IBRGAC permits the use of an alternative gradient equation which takes into account the "chambrage" of the gun. This other equation is known as the chambrage gradient equation [4,5] since it takes into account the effects of a chambrage chamber.

Straight and chambrage chambers are defined in the following manner. A straight or bore-diameter chamber has the same radial distance as the gun bore. A chambrage chamber has a radial distance which is larger than the bore radial distance. This larger diameter is tapered or "necked down", at the forward end of the chamber, to the same radial dimensions of the bore (see Figure 1).

We tested IBRGAC with Lagrange and chambrage gradient equations to be sure that, for data bases that specified a bore-diameter chamber, a calculation with the chambrage gradient gives essentially the same results as the Lagrange gradient. Table 3 indicates that the chambrage gradient reduces to the Lagrange gradient for a bore-diameter chamber configuration.

FIGURE 1



A is the length of the tapered section of the chambrage chamber
B is the overall chamber length
C is the bore diameter
D is the chamber diameter
D/C is defined as the "chambrage"

TABLE 3

COMPARISON OF CALCULATED RESULTS FOR THE LAGRANGE AND CHAMBRAGE GRADIENTS IN A BORE-DIAMETER CHAMBER

Trajectory	IBRGAC (Lagrange)	IBRGAC (chambrage)	% difference
Maximum breech pressure (MPa)	517.58	517.62	0.01%
Maximum mean pressure (MPa)	460.05	460.08	0.01%
Maximum base pressure (MPa)	344.99	345.02	0.01%
Muzzle velocity (m/s)	1576.09	1576.11	0.0012%

III. THE EFFECTS OF CHAMBRAGE

Table 4 demonstrates the effects of chambrage. In Table 4, calculations with IBRGAC are compared with those of XKTC [6], which is a phenomenologically complete two-phase flow interior ballistic computer code which has a history of good agreement with gun firings. IBRGAC is used with the chambrage gradient equation for all of these calculations, since we have seen that it correctly handles both chambrage and bore-diameter chambers. All calculations are for a propellant-mass to projectile-mass ratio of one. The first line of the table compares calculations for a nominal 120-mm weapon with a bore-diameter chamber. We see that the agreement between IBRGAC and XKTC is quite good. For the second line of the table, chambrage has been introduced. The total chamber volume was maintained, but 7.62 cm of chambrage was added, so that the overall chamber length was shortened from 77.6 cm to 54.1 cm. Note the agreement between the codes, the drop in the maximum breech pressure, and the (expected) concomitant drop in the muzzle velocity. The third line of the table results from changing the propellant web so that XKTC predicted the same maximum breech pressure as had been obtained for the bore-diameter case in the first line, 345 Mpa. That same propellant web was then used in IBRGAC. Again, IBRGAC and XKTC agree quite well. By comparing this third line with the first line, we see that a gun with a chambrage chamber can achieve a higher muzzle velocity without increasing its maximum chamber pressure.

TABLE 4

EFFECT OF CHAMBRAGE BETWEEN XKTC AND IBRGAC

Chamber Volume (cm^3)	chambrage	XKTC max breech pressure (MPa)	XKTC muzzle velocity (m/s)	IBRGAC max breech pressure (MPa)	IBRGAC muzzle velocity (m/s)
9832	none	345	1352	346	1363
9832	1.21	310	1303	305	1306
9832	1.21	345	1376	347	1390

This calculated increase in velocity due to chambrage also occurs for optimized gun systems, in which the grain dimensions and propellant mass are varied to maximize muzzle velocity while maintaining a given maximum breech pressure. To illustrate this point, Appendix D documents a calculation in which a bore-diameter gun was optimized for velocity for a maximum breech pressure of 346 MPa. For this case, a muzzle velocity of 1398 m/s was achieved using 8.7 kg of propellant with a web of 0.2299 cm. Appendix E documents a companion optimization calculation for a chambrage chamber, again for a maximum breech pressure of 346 MPa. A muzzle velocity of 1408 m/s was achieved using 8.85 kg of propellant with a web of 0.2276 cm.

Many propellant charges have been designed in the past by using codes with Lagrange gradient equations and modeling bore-diameter chambers. One might ask whether the propellant dimensions that were determined from these calculations were in fact the optimum dimensions for the real, chambrage gun. IBRGA makes this determination easy. If one takes the propellant web of 0.2299 cm from the bore-diameter optimization above and uses it in a chambrage calculation, and further increases the propellant weight to 8.91 kg to restore 346 MPa, one achieves a muzzle velocity of 1408 m/s, the same velocity as was predicted in the optimized chambrage calculation above. Thus we see that past optimizations of propellant web have, in fact, determined nearly optimal propellant web for guns with chambrage. The weight of propellant needed was not so well determined, however.

There are two factors inherent in a chambrage chamber which may account for the increased muzzle velocity which is both observed and calculated. First, the smaller chamber length of a chambrage configuration translates into a smaller pressure gradient for a significant portion of the early part of the ballistic cycle. With this condition, a higher base pressure and an increase in projectile velocity will result. Second, the increased radial dimension of the chamber means a larger amount of expanding gas is available to act on the base of the projectile, for a significantly increased duration, which would also lead to an increase in energy imparted to the projectile.

IV. CONCLUSIONS

1. IBRGA is a simple FORTRAN computer code which incorporates the TTCP lumped-parameter interior ballistic model.

2. Calculations of mass fraction burned which use the propellant form function directly are more computationally efficient than those proposed in the TTCP model.

3. Calculations with IBRGA compare favorably with those from IBHVG2.

4. IBRGA permits the use of a pressure gradient equation which takes chambrage into

account; calculations with IBRGA on the effects of chambrage compare favorably with equivalent XKTC calculations.

5. IBRGA can be used to show that a gun chamber with chambrage will, for the same conditions, give a lower maximum breech pressure, or if the propellant grain dimensions are changed to reproduce the original maximum breech pressure, will give a higher projectile velocity than a bore-diameter chamber.

6. Optimized gun calculations done with either the Lagrange gradient or the chambrage gradient in a bore-diameter chamber, will give nearly-optimal propellant grain dimensions. Thus, previous optimizations with older codes led to proper propellant grain manufacture.

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3. P. S. Gough, "Two-Dimensional, Two-Phase Modeling of Multi-Increment Bagged Artillery Charges," PGA-TR-82-1, Paul Gough Associates, Inc. Portsmouth, NH., 1982.

4. F. W. Robbins, R. D. Anderson and P. S. Gough, "Continued Studies of The Development of a Modified Pressure Gradient Equation for Lumped Parameter Interior Ballistics Codes," 10th International Symposium on Ballistics, Volume 1, October 1987.

5. W. F. Morrison and G. P. Wren, "A Lumped Parameter Description of Liquid Injection in A Regenerative Liquid Propellent Gun," Proceedings of the 23rd JANNAF Combustion Meeting, CPIA Publication 457, Vol II, pp 464-489, October 1986.

6. P. S. Gough, Contractor Report, DAAK 11-85-D-0002, in preparation.

APPENDIX A

Interior Ballistic Equations

IBRGA (and also IBHVG2) relies on mathematical models in which only the most essential forces are included. Following is a compilation of the relations which make up the interior ballistics governing equations.

1. The equation of motion of the center of mass of the projectile is

$$\dot{v}_p = \frac{A(P_b - br - P_g)}{m_p}, \tag{1.1}$$

where the area of the base of the projectile including the appropriate portion of the rotating band is

$$A = \frac{\pi}{4} D_b{}^2, \tag{1.2}$$

$$\text{where } D_b{}^2 = \left\{ \frac{GLR\ DG^2}{GLR + 1} + \frac{DL^2}{GLR + 1} \right\}. \tag{1.3}$$

The pressure on the base of the projectile, P_b, including the approximate pressure gradient effect is,

for the Lagrange gradient,

$$P_b = \frac{\left\{ \bar{P} + \frac{C_T(br + P_g)}{3m_p} \right\}}{\left\{ 1 + \frac{C_T}{3m_p} \right\}}, \tag{1.4}$$

and for the chambrage gradient

$$P_b = \frac{\bar{P} - \delta}{\gamma}, \tag{1.5}$$

$$\text{where} \quad \delta = -a_1 J_1 - bJ_2 + \frac{J_3 a_1 + J_4 b}{V(z_p)}, \tag{1.6}$$

$$\text{and} \quad \gamma = 1 - a_2 J_1 + \frac{J_3 a_2}{V(z_p)}, \tag{1.7}$$

$V(z_p)$ is the volume up to the base of the projectile ,

and z_p is the distance from the breech to the base of the projectile.

$$a_1 = \frac{C_T A}{V^2(z_p)} \left[\frac{A v_p{}^2}{V(z_p)} + \frac{A(br + P_g)}{m_p} \right], \tag{1.8}$$

$$a_2 = \frac{-C_T A^2}{m_p V^2(z_p)}, \tag{1.9}$$

$$\text{and } b = \frac{-C_T {v_p}^2}{2} \frac{A^2}{V^3(z_p)} . \tag{1.10}$$

Also,

$$J_1 = \int_0^{z_p} \frac{V(z)}{A(z)} dz , \tag{1.11}$$

$$J_2 = \frac{V^2(z)}{A^2(z)} , \tag{1.12}$$

$$J_3 = \int_0^{z_p} A(z) J_1(z) dz , \tag{1.13}$$

$$J_4 = \int_0^{z_p} A(z) J_2(z) dz , \tag{1.14}$$

where $A(z)$ is the area at distance z from the breech,

$V(z)$ is the volume at distance z from the breech,

and J_1, J_2, J_3, J_4 are numerically evaluated at z_p.

2. The velocity of the center of mass of the projectile is

$$v_p = \int_0^t \dot{v}_p dt . \tag{2.1}$$

3. The breech pressure P_o is ,

for the Lagrange gradient ,

$$P_o = P_b + \frac{C_T}{2m_p}(P_b - br - P_g) \tag{3.1}$$

and for the chambrage gradient

$$P_0 = P_b(1 - a_2 J_1) - a_1 J_1 - b J_2 . \tag{3.2}$$

4. The travel of the projectile is

$$x = \int_0^t v_p dt + \int_0^t v_{rp} dt . \tag{4.1}$$

5. The mass fraction burning rate of the ith propellant is

$$\dot{Z}_i = \frac{S_i r_i}{V_{g_i}} , \tag{5.1}$$

where r_i and S_i are the instantaneous values of the burning rate and surface area, respectively, and V_{g_i} is the initial grain volume.

The linear burning rate r_i is given by

$$r_i = \beta_i \bar{P}^{\alpha_i} . \tag{5.2}$$

6. The fraction of mass burned of the ith propellant is

$$Z_i = \int_0^t \dot{Z}_i \, dt \,, \tag{6.1}$$

$$\text{or } Z_i = \frac{v_t}{V_{gi}} \,, \tag{6.2}$$

where v_t is the instantaneous volume of the propellant burned calculated from the distance burned into the propellant given by $\int_0^t r_i \, dt$.

7. The space-mean pressure $\overline{P}$ (Noble-Able Law) is

$$\overline{P} = \frac{T}{V_c} \left[\sum_i^n \frac{F_i C_i Z_i}{T_{0i}} + \frac{F_I C_I}{T_{0I}} \right] , \tag{7.1}$$

where the number of propellants is n and the volume available for gases is

$$V_c = V_o + A x - \sum_i^n \frac{C_i}{\rho_i} (1 - Z_i) - \sum_i^n C_i b_i Z_i - C_I b_I \,, \tag{7.2}$$

and the temperature of the gases is given by

$$T = \frac{\left\{ \sum_i^n \frac{F_i C_i Z_i}{(\gamma_i - 1)} + \frac{F_I C_I}{(\gamma_I - 1)} - E_{pt} - E_{pr} - E_p - E_{br} - E_r - E_d - E_h \right\}}{\left\{ \sum_i^n \frac{F_i C_i Z_i}{(\gamma_i - 1) T_{0i}} + \frac{F_I C_I}{(\gamma_I - 1) T_{0I}} \right\}} \,. \tag{7.3}$$

The energy loss due to projectile translation is

$$E_{pt} = \frac{m_p v_p^{\,2}}{2} \,, \tag{7.4}$$

the energy loss due to projectile rotation is

$$E_{pr} = \frac{\pi^2 m_p v_p^{\,2} T w^2}{4} \,, \tag{7.5}$$

the energy loss due to propellant gas and unburned propellant motion is ,

for the Lagrange gradient ,

$$E_p = \frac{C_T v_p^{\,2}}{6} \,, \tag{7.6}$$

and for the chambrage gradient

$$E_p = \frac{C_T v_p^{\,2}}{2} \, \frac{A^2 J_4}{V^3(z_p)} \,. \tag{7.7}$$

The energy loss for work against bore resistance due to engraving and friction is

$$E_{br} = A \int_0^t br\, v_p \, dt \,, \tag{7.8}$$

the energy loss due to recoil is

$$E_r = \frac{m_{rp}\,(v_{rp})^2}{2} \,, \tag{7.9}$$

and the energy lost due to air resistance is

$$E_d = A \int_0^t v_p \, P_g \, dt \,. \tag{7.10}$$

The energy lost due to heat transfer to the chamber walls is given by

$$E_h = \int_0^t \dot{Q} \, dt \,, \tag{7.11}$$

with

$$\dot{Q} = Awh\,(T - T_c) \,, \tag{7.12}$$

where

$$Aw = \frac{V_o}{A} \pi D_b + 2A + \pi D_b \, x \,, \tag{7.13}$$

and

$$h = \lambda \, \overline{C}_p \, \overline{\rho} \, \overline{v} + h_o \,, \tag{7.14}$$

where the Nordheim heat transfer coefficient λ is

$$\lambda = [\, 13.2 + 4 \log 10 [\, 100.\, D_b \,]]^{-2} \,, \tag{7.15}$$

and

$$\overline{v} = \frac{1}{2} v_p \,, \tag{7.16}$$

$$\overline{\rho} = \frac{\left\{ \sum_i^n C_i \, Z_i + C_I \right\}}{V_c} \,. \tag{7.17}$$

$$\text{Since} \quad C_{p_i} = \frac{F_i \, \gamma_i}{(\gamma_i - 1)\, T_{o_i}} \,, \tag{7.18}$$

$$\overline{C}_p = \frac{\left\{ \sum_i^n \frac{F_i \gamma_i C_i Z_i}{(\gamma_i - 1)\, T_{o_i}} dt + \frac{F_I \gamma_I C_I}{(\gamma_I - 1)\, T_{o_I}} \right\}}{\left\{ \sum_i^n C_i Z_i + C_I \right\}} \,. \tag{7.19}$$

Thus the temperature of the chamber wall is

$$T_c = \frac{E_h + f E_{br}}{C_{pw}\ \rho w\ Aw\ Dw} + T_o\ , \tag{7.20}$$

where T_o is the initial temperature of the wall.

8. The equation of motion for the recoiling parts (See figure A.) is

$$\dot{v}_{rp} = \left[\frac{A}{m_{rp}}\right] \left(P_o - \frac{RP}{A} - br\right)\ , \tag{8.1}$$

where

$$\dot{v}_{rp} = 0 \quad \text{until} \quad P_o > \frac{RP_o}{A} + br\ . \tag{8.2}$$

When

$$P_o = \frac{RP_o}{A}\ , \quad t = t_{r_o} \ \text{ and } \ t_r = t - t_{r_o}\ , \tag{8.3}$$

and if

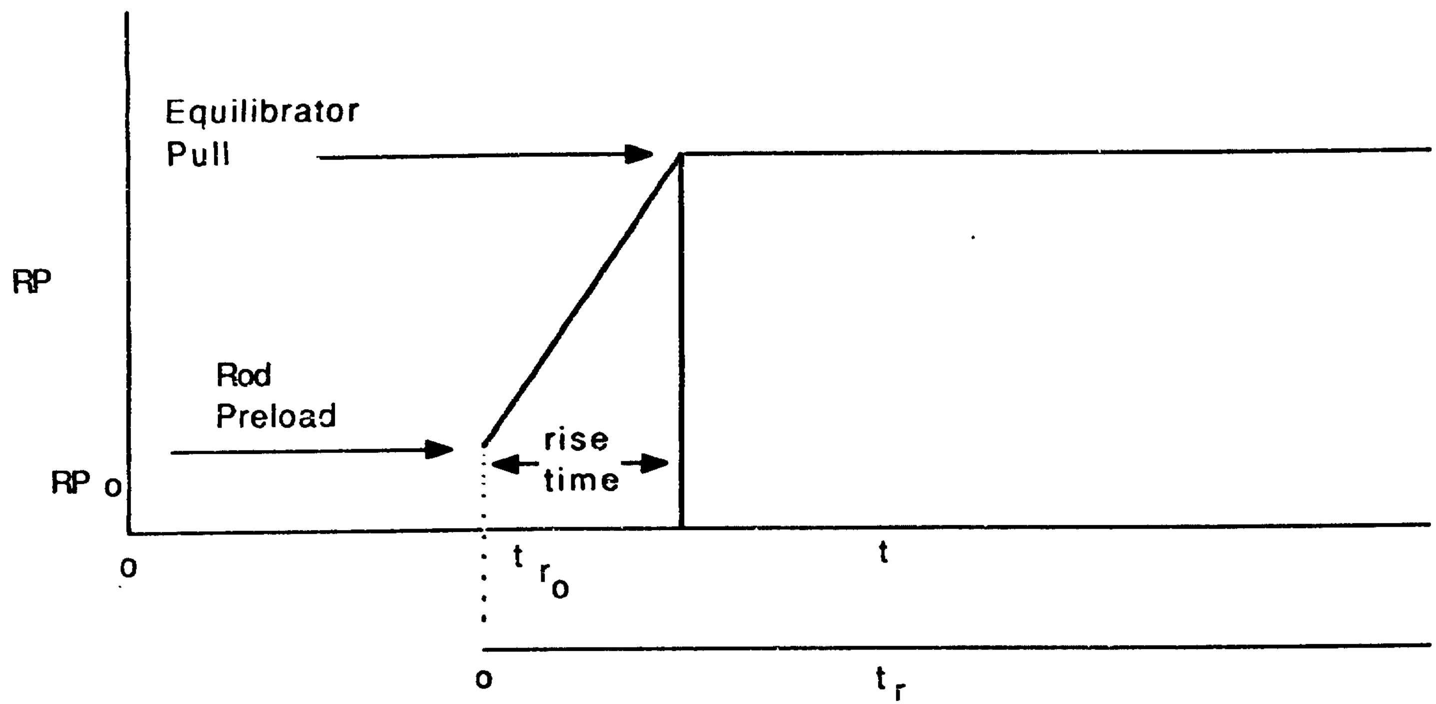
$$\dot{v}_{rp} < 0\ ,$$

$$\dot{v}_{rp} = 0\ . \tag{8.4}$$

9. The velocity of the recoiling parts in the ground reference frame is

$$v_{rp} = \int_o^t \dot{v}_{rp}\, dt\ . \tag{9.1}$$

WEAPON RECOIL



TIME OF RECOIL

FIGURE A

LIST OF SYMBOLS

symbol	definition	units
A	area of base of projectile including appropriate portion of rotating band	m^2
Aw	chamber wall area plus area of gun tube wall exposed to propellant gases	m^2
$A(z)$	area at a distance z from the breech	m^2
b_i	covolume of ith propellant	m^3/kg
b_I	covolume of igniter	m^3/kg
br	bore resistance due to friction and engraving	Pa
C_i	initial mass of ith propellant	kg
C_I	initial mass of igniter	kg
$\bar{C}_p$	specific heat at constant pressure of propellant gas	J/kg-K
C_{pi}	specific heat at constant pressure of ith propellant (over temperature range T to T_{oi})	J/kg-K
$C_{p\,w}$	heat capacity of steel of chamber wall	J/kg-K
C_T	total mass of propellants and igniter	kg
D_b	diameter of bore	m
DG	diameter of grooves	m
DL	diameter of lands	m
Dw	chamber wall thickness	m
$E_{b\,r}$	energy lost to work against bore resistance due to friction and engraving	J
E_d	energy lost to air resistance	J
E_h	energy loss from heat transfer to chamber wall	J
E_p	energy lost to propellant gas and unburned propellant motion	J
$E_{p\,r}$	energy loss due to projectile rotation	J
$E_{p\,t}$	energy loss due to projectile translation	J
E_r	energy loss due to recoil	J
f	fraction of work done against bore friction that preheats chamber	none
F_i	force per unit mass of ith propellant	J/kg
F_I	force per unit mass of igniter propellant	J/kg
GLR	groove to land ratio	none
h	heat transfer coefficient of Nordheim, Soodak, and Nordheim	$watt/m^2$
m_p	mass of projectile	kg
m_{rp}	mass of recoiling parts	kg

$\bar{P}$	space mean pressure	Pa
P_b	pressure on base of projectile	Pa
P_g	pressure of gas or air ahead of projectile	Pa
P_o	breech pressure	Pa
$\dot{Q}$	heat flux to the chamber wall	w
r_i	linear burning rate of ith propellant	m/s
RP	resistive force to projectile motion	N
S_i	surface area of partially burned ith propellant grain	m^2
t	time	s
t_r	recoil time	s
T	mean temperature of propellant gases	K
T_c	temperature of chamber wall	K
T_{oi}	adiabatic flame temperature of ith propellant	K
T_{oI}	adiabatic flame temperature of igniter propellant	K
T_o	initial temperature of chamber wall	K
Tw	twist of rifling	turns/caliber
$V(z)$	volume at distance z from the breech	m^3
$V(z_p)$	volume up to the base of the projectile	m^3
$\bar{v}$	mean gas velocity	m/s
v_p	velocity of projectile	m/s
$\dot{v}_p$	acceleration of projectile	m/s^2
v_{r_p}	velocity of recoiling parts	m/s
v_c	volume behind projectile available for propellant gas	m^3
V_{gi}	volume of an unburned ith propellant grain	m^3
v_o	volume of an empty cannon chamber	m^3
v_t	instantaneous volume of propellant burned	m^3
x	travel of projectile	m
Z_i	fraction of mass burned of the ith propellant	none
$\dot{Z}_i$	mass fraction burning rate for ith propellant	s^{-1}
z_p	distance from the breech to the base of the projectile	m
α_i	burning rate exponent for the ith propellant	none
β_i	burning rate coefficient for the ith propellant	m/s-Pa^{α_i}
γ_i	ratio of specific heats for ith propellant	none
γ_I	ratio of specific heats for igniter	none
λ	Nordheim heat transfer coefficient	none
$\bar{\rho}$	mean gas density	kg/m^3
ρ_i	density of ith propellant	kg/m^3
ρw	density of chamber wall steel	kg/m^3

APPENDIX B

Source code listing of the IBRGAC program.

```
      program ibrgac
      character bdfile*10,outfil*10
      dimension br(10),trav(10),rp(10),tr(10),forcp(10),tempp(10),covp(
     &10)
      dimension chwp(10),rhop(10),gamap(10),nperfs(10),glenp(10),pdpi(10
     &),p dpo(10),gdiap(10),dbpcp(10),alpha(10,10),beta(10,10),
     &pres(10,10)
      dimension a(4),b(4),ak(4),d(20),y(20),p(20),z(20),frac(10),surf(10
     &),nbr(10),ibo(10)
      real lambda,j1zp,j2zp,j3zp,j4zp
      dimension chdist(5),chdiam(5),bint(4)
c     call gettim(ihr,imin,isec,ihuns)
      pi=3.14159
      write(*,15)
15    format(' input name of data file to be used as input ')
      read(*,10)bdfile
10    format(a10)
      open(unit=2,err=999,file=bdfile,status='old',iostat=ios)
      rewind 2
      write(*,25)
25    format(' input name of output file ')
      read(*,10)outfil
      open(unit=3,err=998,file=outfil,status='new')
      write(3,16)bdfile
16    format(' THE INPUT FILE IS ',a10)
      read(2,*,end=20,err=30)cham,grve,aland,glr,twst,travp,igrad
      if(igrad.gt.1)go to 51
      write(3,55)
55    format(1x,'using Lagrange pressure gradient')
      go to 52
c     define chambrage assumes nchpts=number of points to define
c     chamber > or = 2 < or = 5 (?),chdiam(I) defines chamber diameter
c     at chdist (I) chamber distance.  chdiam(nchpts) is assumed to be
c     the bore diameter and chdist(i) is assumed to be 0, i.e. at the
c     breech. Assumes truncated cones.
51    write(3,47,err=30)
47    format(1x,'Using chambrage pressure gradient')
      read(2,*,end=20,err=30)nchpts,(chdist(I),chdiam(I),I=1,nchpts)
      write(3,53,err=30)(chdist(I),chdiam(I),I=1,nchpts)
53    format(///,'   chamber distance cm   chamber diameter cm',/(5x,e14
     &.6,5x,e14.6))
      do 54 I=1,nchpts
      chdist(I)=0.01*chdist(I)
54    chdiam(I)=0.01*chdiam(I)
c     calculate chamber integrals and volume
      if(nchpts.gt.5) write(3,44,err=30)
44    format(1x,'use first 5 points')
      if(nchpts.gt.5)nchpts=5
      bore=chdiam(nchpts)
      if(chdist(1).ne.0.0)write(3,45,err=30)
45    format(1x,' # points ? ')
```

```
      chdist(1)=0.0
      pi3=pi/3.0
      b1=0.0
      b2=0.0
      b3=0.0
      b4=0.0
      points=25.0
56    points=points+points
      step=chdist(nchpts)/points
      zz=0.0
      bint(1)=0.0
      bint(3)=0.0
      bint(4)=0.0
      bvol=0.0
      r2=0.5*chdiam(1)
      k=1
      j=int(points+0.5)
      do 57 I=1,j
      zz=zz+step
      if(k.eq.nchpts-1)go to 46
      do 58 I1=k,nchpts-1
      if(zz.gt.chdist(I1).and. zz.lt.chdist(I1+1))go to 59
58    continue
      I1=nchpts-1
59    k=I1
46    diam=(zz-chdist(k))/(chdist(k+1)-chdist(k))
      diam=chdiam(k)+diam*(chdiam(k+1)-chdiam(k))
      r1=0.5*diam
      area=pi*(r1+r2)*(r1+r2)/4.
      bvol=bvol+step*pi3*(r1*r1+r1*r2+r2*r2)
      bint(1)=bint(1)+step*bvol/area
      bint(3)=bint(3)+step*area*bint(1)
      bint(4)=bint(4)+step*bvol*bvol/area
57    r2=r1
      temp=abs(1.0-b1/bint(1))
      if(abs(1.0-b3/bint(3)).gt.temp)temp=abs(1.0-b3/bint(3))
      if(abs(1.0-b4/bint(4)).gt.temp)temp=abs(1.0-b4/bint(4))
      if(temp.le.0.001)go to 41
      b1=bint(1)
      b3=bint(3)
      b4=bint(4)
      go to 56
41    cham=bvol*1.e6
c     write(3,47,err=30)bint(1),bint(3),bint(4)
c     format(1x,'bint 1 = ',e14.6,'  bint 3 = ',e14.6,'  bint 4 = ',e14.
c    &6)
      chmlen=chdist(nchpts)
52    write(3,40,err=30)cham,grve,aland,glr,twst,travp
40    format(1x,'chamber volume cm**3',e14.6,/'  groove diam cm',e14.6,/
     &' land diam cm',e14.6,/'  groove/land ratio',e14.6,/'  twist turns
     &/caliber ',e14.6,/'  projectile travel cm',e14.6///)
      cham=cham*1.e-6
      grve=grve*1.e-2
      aland=aland*1.e-2
      travp=travp*1.e-2
```

```
      read(2,*,end=20,err=30)prwt,iair,htfr,pgas
      write(3,50,err=30)prwt,iair,htfr,pgas
50    format(1x,'projectile mass kg',e14.6,/' switch to calculate energ
     &y lost to air resistance J',i2,/' fraction of work against bore u
     &sed to heat the tube',e14.6/1x,' gas pressure Pa' ,e14.6)

      read(2,*,end=20,err=30)npts,(br(i),trav(i),i=1,npts)
      write(3,60,err=30)npts,(br(i),trav(i),i=1,npts)
60    format(1x,'number barrel resistance points',i2,/' bore resistance
     & MPa - travel cm'/(1x,e14.6,e14.6))
      write(3,65)
      do 62 i=1,npts
      br(i)=br(i)*1.e6
      trav(i)=trav(i)*1.e-2
62    continue
65    format(1x)
      read(2,*,end=20,err=30)rcwt,nrp,(rp(i),tr(i),i=1,nrp)
      write(3,70,err=30)rcwt,nrp,(rp(i),tr(i),i=1,nrp)
70    format(1x,' mass of recoiling parts kg',e14.6,/' number of recoi
     &l point pairs',i2,/' recoil force N',' recoil time sec'/,(1x,e14
     &.6,3x,e14.6))
      write(3,65)
      read(2,*,end=20,err=30)ho,tshl,cshl,twal,hl,rhocs
      write(3,75,err=30)ho,tshl,cshl,twal,hl,rhocs
75    format(1x,' free convective heat transfer coefficient w/cm**2 K',
     &e14.6,/' chamber wall thickness cm',e14.6,/' heat capacity of st
     &eel of chamber wall J/g K',e14.6,/' initial temperature of chambe
     &r wall K',e14.6,/' heat loss coefficient',e14.6,/' density of ch
     &amber wall steel g/cm**3',e14.6//)
      ho=ho/1.e-4
      tshl=tshl*1.e-2
      cshl=cshl*1.e+3
      rhocs=rhocs*1.e-3/1.e-6
      read(2,*,end=20,err=30)forcig,covi,tempi,chwi,gamai
      write(3,85,err=30)forcig,covi,tempi,chwi,gamai
85    format(1x,' impetus of igniter propellant J/g',e14.6,/' covolume
     & of igniter cm**3/g',e14.6,/' adiabatic flame temperature of igni
     &ter propellant K',e14.6,/' initial mass of igniter kg',e14.6,/' r
     &atio of specific heats for igniter',e14.6//)
      forcig=forcig*1.e+3
      covi=covi*1.e-6/1.e-3
      read(2,*,end=20,err=30)nprop,(forcp(i),tempp(i),covp(i),chwp(i),
     &rhop(i),gamap(i),nperfs(i),glenp(i),pdpi(i),pdpo(i),gdiap(i),dbpcp
     &(i),i=1,nprop)
      write(3,95,err=30)(i,forcp(i),tempp(i),covp(i),chwp(i)
     &,rhop(i),gamap(i),nperfs(i),glenp(i),pdpi(i),pdpo(i),gdiap(i),dbpc
     &p(i),I=1,nprop)
95    format((' for propellant number',i2,/' impetus of propellant J/g
     &',e14.6,/' adiabatic temperature of propellant K',e14.6,/' covol
     &ume of propellant cm**3/g',e14.6/' initial mass of propellant kg'
     &,e14.6/' density of propellant g/cm**3',e14.6/' ratio of specifi
     &c heats for propellant',e14.6/' number of perforations of propell
     &ant',i2/' length of propellant grain cm',e14.6/' diameter of inn
     &er perforation in propellant grains cm',e14.6/' diameter of outer
     &perforation of propellant grains cm',e14.6/' outside diameter of
```

```
     &propellant grain cm',e14.6/'  distance between perf centers cm',e1
     &4.6)//)
      tmpi=0.0
      do 96 i=1,nprop
      forcp(i)=forcp(i)*1.e+3
      covp(i)=covp(i)*1.e-6/1.e-3
      rhop(i)=rhop(i)*1.e-3/1.e-6
      glenp(i)=glenp(i)*0.01
      pdpi(i)=pdpi(i)*0.01
      pdpo(i)=pdpo(i)*0.01
      gdiap(i)=gdiap(i)*0.01
      dbpcp(i)=dbpcp(i)*0.01
      tmpi=tmpi+chwp(i)
96    continue
      tmpi=tmpi+chwi
      do 97 j=1,nprop
      read(2,*,end=20,err=30)nbr(j),(alpha(j,i),beta(j,i),pres(j,i),
     &i=1,nbr(j))
      write(3,110,err=30)nbr(j),(alpha(j,i),beta(j,i),pres(j,i),
     &i=1,nbr(j))
110   format(1x,'number of burning rate points',i2/3x,'  exponent',8x,'
     & coefficient',10x,'  pressure'/5x,'-',15x,'cm/sec-MPa**ai',10x,'MP
     &a',/(1x,e14.6,5x,e14.6,15x,e14.6))
      do 112 i=1,nbr(j)
      beta(j,i)=beta(j,i)*1.e-2
      pres(j,i)=pres(j,i)*1.e6
112   continue
97    continue
      write(3,65)
      read(2,*,end=20,err=30)deltat,deltap,tstop
      write(3,120,err=30)deltat,deltap,tstop
120   format(1x,'time increment msec',e14.6,'  print increment msec',e14
     &.6/1x,'time to stop calculation msec ',e14.6)
      write(*,130)
      deltat=deltat*0.001
      deltap=deltap*0.001
      tstop=tstop*.001
130   format(1x,'the data has been read')
      if(igrad.gt.1)go to 131
      bore=(glr*grve*grve+aland*aland)/(glr+1.)
      bore=sqrt(bore)
131   areab=pi*bore*bore/4.
      lambda=1./((13.2+4.*log10(100.*bore))**2)
      pmaxm=0.0
      pmaxbr=0.0
      pmaxba=0.0
      tpmaxm=0.0
      tpmaxbr=0.0
      tpmaxba=0.0
      tpmax=0.0
      a(1)=0.5
      a(2)=1.-sqrt(2.)/2.
      a(3)=1.+sqrt(2.)/2.
      a(4)=1./6.
      b(1)=2.
```

```
      b(2)=1.
      b(3)=1.
      b(4)=2.
      ak(1)=0.5
      ak(2)=a(2)
      ak(3)=a(3)
      ak(4)=0.5
      vp0=0.0
      tr0=0.0
      tcw=0.0
      do 5 i=1,nprop
      ibo(i)=0
  5   vp0=chwp(i)/rhop(i)+vp0
      volgi=cham-vp0-chwi*covi
      pmean=forcig*chwi/volgi
      volg=volgi
      volgi=volgi+vp0
      wallt=twal
      ptime=0.0
      ibrp=8
      z(3)=1.
      nde=ibrp+nprop
      write(3,132)areab,pmean,vp0,volgi
132   format(1x,'area bore m^2 ',e16.6,' pressure from ign Pa',e16.6,/
     &1x,' volume of unburnt prop m^3 ',e16.6,' init cham vol-cov ign m
     &^3 ',e16.6)
      write(3,6)
6     format(1x,'   time        acc          vel          dis          mpress
     &   pbase       pbrch     ')
      isw1=0
19    continue
      do 11 J=1,4
c     FIND BARREL RESISTANCE
      do 201 k=2,npts
      if(y(2)+y(7).ge.trav(k))go to 201
      go to 203
201   continue
      k=npts
203   resp=(trav(k)-y(2)-y(7))/(trav(k)-trav(k-1))
      resp=br(k)-resp*(br(k)-br(k-1))
c     FIND MASS FRACTION BURNING RATE
      do 211 k=1,nprop
      if(ibo(k).eq.1)goto211
      call prf017(pdpo(k),pdpi(k),gdiap(k),dbpcp(k),glenp(k),surf(k),fra
     &c(k),y(ibrp+k),nperfs(k),u)
      if(surf(k).lt.1.e-10) ibo(k)=1
211   continue
      k=nprop
c     ENERGY LOSS TO PROJECTILE TRANSLATION
      elpt=prwt*y(1)*y(1)/2.
c     ENERGY LOSS DUE TO PROJECTILE ROTATION
      elpr=pi*pi*prwt*y(1)*y(1)/4.*twst*twst
c     ENERGY LOSS DUE TO GAS AND PROPELLANT MOTION
      if(igrad.le.1)go to 214
      pt=y(2)+y(7)
```

```
      vzp=bvol+areab*pt
      j4zp=bint(4)+((bvol+areab*pt)**3-bvol**3)/3./areab/areab
      elgpm=tmpi*y(1)*y(1)*areab*areab*j4zp/2./vzp/vzp/vzp
      go to 216
214   elgpm=tmpi*y(1)*y(1)/6.
c     ENERGY LOSS FROM BORE RESISTANCE
216   elbr=y(4)
      z(4)=areab*resp*y(1)
c     ENERGY LOSS DUE TO RECOIL
      elrc=rcwt*y(6)*y(6)/2.
c     ENERGY LOSS DUE TO HEAT LOSS
      areaw=cham/areab*pi*bore+2.*areab+pi*bore*(y(2)+y(7))
      avden=0.0
      avc=0.0
      avcp=0.0
      z18=0
      z19=0
      do 213 k=1,nprop
      z18=forcp(k)*gamap(k)*chwp(k)*frac(k)/(gamap(k)-1.)/tempp(k)+z18
      z19=chwp(k)*frac(k)+z19
      avden=avden+chwp(k)*frac(k)
213   continue
      avcp=(z18+forcig*gamai*chwi/(gamai-1.)/tempi)/(z19+chwi)
      avden=(avden+chwi)/(volg+covl)
      avvel=.5*y(1)
      htns=lambda*avcp*avden*avvel+ho
      z(5)=areaw*htns*(tgas-wallt)*hl
      elht=y(5)
      wallt=(elht+htfr*elbr)/cshl/rhocs/areaw/tshl+twal
c     write(3,*)lambda,avcp,avden,avvel,ho,areaw,htns,tgas,wallt,hl,z(5)
c    &,elht
c     ENERGY LOSS DUE TO AIR RESISTANCE
      air=iair
      z(8)=y(1)*pgas*air
      elar=areab*y(8)
c     RECOIL
      z(6)=0.0
      if(pbrch.le.rp(1)/areab)go to 221
      rfor=rp(2)
      if(y(3)-tr0.ge.tr(2))go to 222
      rfor=(tr(2)-(y(3)-tr0))/(tr(2)-tr(1))
      rfor=rp(2)-rfor*(rp(2)-rp(1))
222   z(6)=areab/rcwt*(pbrch-rfor/areab-resp)
      if(y(6).lt.0.0)y(6)=0.0
      z(7)=y(6)
      goto 223
221   tr0=y(3)
223   continue
c     CALCULATE GAS TEMPERATURE
      eprop=0.0
      rprop=0.0
      do 231 k=1,nprop
      eprop=eprop+forcp(k)*chwp(k)*frac(k)/(gamap(k)-1.)
      rprop=rprop+forcp(k)*chwp(k)*frac(k)/(gamap(k)-1.)/tempp(k)
231   continue
```

```
      tenergy=elpt+elpr+elgpm+elbr+elrc+elht+elar
      tgas=(eprop+forcig*chwi/(gamai-1.)-elpt-elpr-elgpm-elbr-elrc-elht
     &-elar)/(rprop+forcig*chwi/(gamai-1.)/tempi)
c     FIND FREE VOLUME
      v1=0.0
      cov1=0.0
      do 241 k=1,nprop
      v1=chwp(k)*(1.-frac(k))/rhop(k)+v1
      cov1=cov1+chwp(k)*covp(k)*frac(k)
241   continue
      volg=volgi+areab*(y(2)+y(7))-v1-cov1
c     CALCULATE MEAN PRESSURE
      r1=0.0
      do 251 k=1,nprop
      r1=r1+forcp(k)*chwp(k)*frac(k)/tempp(k)
251   continue
      pmean=tgas/volg*(r1+forcig*chwi/tempi)
259   resp=resp+pgas*air
      if(igrad.le.1)go to 252
      if(isw1.ne.0)go to 253
      pbase=pmean
      pbrch=pmean
      if(pbase.gt.resp+1.)isw1=1
      go to 257
c     USE CHAMBRAGE PRESSURE GRADIENT EQUATION
253   j1zp=bint(1)+(bvol*pt+areab/2.*pt*pt)/areab
      j2zp=(bvol+areab*pt)**2/areab/areab
      j3zp=bint(3)+areab*bint(1)*pt+bvol*pt*pt/2.+areab*pt*pt*pt/6.
      a2t=-tmpi*areab*areab/prwt/vzp/vzp
      alf=1.-a2t*j1zp
      a1t=tmpi*areab*(areab*y(1)*y(1)/vzp+areab*resp/prwt)/vzp/vzp
      bt=-tmpi*y(1)*y(1)*areab*areab/2./vzp/vzp/vzp
      bata=-a1t*j1zp-bt*j2zp
      gamma=alf+a2t*j3zp/vzp
      delta=bata+a1t*j3zp/vzp+bt*j4zp/vzp
c     calculate base pressure
      pbase=(pmean-delta)/gamma
c     calculate breech pressure
      pbrch=alf*pbase+bata
      go to 254
c     USE LAGRANGE PRESSURE GRADIENT EQUATION
252   if(isw1.ne.0)go to 256
      if(pmean.lt.resp)resp=pmean
c     CALCULATE BASE PRESSURE
256   pbase=(pmean+tmpi*resp/3./prwt)/(1.+tmpi/3./prwt)
      if(pbase.gt.resp+1.)isw1=1
c     CALCULATE BREECH PESSURE
      pbrch=pbase+tmpi/2./prwt*(pbase-resp)
c     CALCULATE PROJECTILE ACCELERATION
254   z(1)=areab*(pbase-resp)/prwt
      if(z(1).lt.0.0)go to 257
      go to 258
257   if(isw1.eq.0)z(1)=0.0
258   if(y(1).lt.0.0)y(1)=0.0
      z(2)=y(1)
```

```
c       GET BURNING RATE
        do 264 m=1,nprop
        z(ibrp+m)=0.0
        if(ibo(m).eq.1) goto 264
        do 262 k=1,nbr(m)
        if(pmean.gt.pres(m,k))go to 262
        go to 263
262     continue
        k=nbr(m)
263     z(ibrp+m)=beta(m,k)*(pmean*1.e-6)**alpha(m,k)
264     continue
        do 21 i=1,nde
        d(i)=(z(i)-b(j)*p(i))*a(j)
        y(i)=deltat*d(i)+y(i)
        p(i)=3.*d(i)-ak(j)*z(i)+p(i)
 21     continue
 11     continue
        t=t+deltat
        if(pmaxm.gt.pmean)go to 281
        pmaxm=pmean
        tpmaxm=y(3)
281     if(pmaxba.gt.pbase)go to 282
        pmaxba=pbase
        tpmaxba=y(3)
282     if(pmaxbr.gt.pbrch)go to 283
        pmaxbr=pbrch
        tpmaxbr=y(3)
283     continue
        if(y(3).lt.ptime)go to 272
        ptime=ptime+deltap
        write(3,7)y(3),z(1),y(1),y(2),pmean,pbase,pbrch
7       format(1x,7e11.4)
316     format(1x)
272     continue
        if(t.gt.tstop)goto 200
        if(y(2).gt.travp)go to 200
        rmvelo=y(1)
        tmvelo=y(3)
        disto=y(2)
        go to 19
200     write(3,311)t,y(3)
311     format(1x,' deltat t', e14.6, ' intg t',e14.6)
        write(3,312)pmaxm,tpmaxm
312     format(1x,'PMAXMEAN Pa ',e14.6,' time at PMAXMEAN sec ',e14.6)
        write(3,313)pmaxba,tpmaxba
313     format(1x,'PMAXBASE Pa ',e14.6,' time at PMAXBASE sec ',e14.6)
        write(3,314)pmaxbr,tpmaxbr
314     format(1x,'PMAXBREECH Pa ',e14.6,' time at PMAXBREECH sec ',e14.6)
        if(y(2).le.travp)go to 303
        dfract=(travp-disto)/(y(2)-disto)
        rmvel=(y(1)-rmvelo)*dfract+rmvelo
        tmvel=(y(3)-tmvelo)*dfract+tmvelo
        write(3,318)rmvel,tmvel
318     format(1x,'muzzle VELOCITY m/s ',e14.6,' time of muzzle velocity s
       &ec ',e14.6)
```

```
      goto 319
303   write(3,327)y(1),y(3)
327   format(1x,'velocity of projectile m/s ',e14.6,' at this time msec
     &',e14.6)
319   efi=chwi*forcig/(gamai-1.)
      efp=0.0
      do 315 i=1,nprop
      efp=efp+chwp(i)*forcp(i)/(gamap(i)-1.0)
315   continue
      tenerg=efi+efp
      write(3,317)tenerg
317   format(1x,'total initial energy available J = ',e14.6)
      tengas=chwi*forcig*tgas/(gamai-1.)/tempi
      do 135 i=1,nprop
      tengas=(frac(i)*chwp(i)*forcp(i)*tgas/tempp(i)/(gamap(i)-1.))+teng
     &as
      write(3,328)i,frac(i)
328   format(' FOR PROPELLANT ',I2,' MASSFRACT BURNT IS ',e14.6)
135   continue
      write(3,136)tengas
136   format(1x,'total energy remaining in gas J= ',e14.6)
      write(3,320)elpt
320   format(1x,'energy loss from projectile translation J= ',e14.6)
      write(3,321)elpr
321   format(1x,'energy loss from projectile rotation J= ',e14.6)
      write(3,322)elgpm
322   format(1x,'energy lost to gas and propellant motion J= ',e14.6)
      write(3,323)elbr
323   format(1x,'energy lost to bore resistance J= ',e14.6)
      write(3,324)elrc
324   format(1x,'energy lost to recoil J= ',e14.6)
      write(3,325)elht
325   format(1x,'energy loss from heat transfer J= ',e14.6)
      write(3,326)elar
326   format(1x,'energy lost to air resistance J= ',e14.6)
c     call gettim(ihro,imino,iseco,ihunso)
c     time=(ihro-ihr)*3600.+(imino-imin)*60.+(iseco-isec)+(ihunso-ihuns)
c    &/100.
c     write(3,*)time
      stop
 20   write(*,140)
140   format(1x,'end of file encounter')
      stop
 30   write(*,150)
999   continue
998   continue
150   format(1x,'read or write error')
      stop
      end
      SUBROUTINE PRF017(P,P1,D,D1,L,SURF,MASSF,X,NP,u)
      IMPLICIT REAL*4(A-Z)
C
C     P=OUTER PERF DIA
C     P1=INNER PERF DIA
C     D=OUTER DIA
```

```
C       D1=DISTANCE BETWEEN PERF CENTRES
C       L=GRAIN LENGTH
C       NP=NUMBER OF PERFS
C
C       SURF=OUTPUT SURFACE AREA
C       MASSF=OUTPUT MASS FRACTION OF PROPELLANT BURNER
C
C       W=WEB BETWEEN OUTER PERFS
C       WO=OUTER WEB
C       W1=WEB BETWEEN OUTER AND INNER PERFS
C       W4=MINIMUM WEB
C
        INTEGER ITYM,NP
        DATA PI,SQRT3/3.14159,1.732051/,ITYM/0/
        DATA HAFPI,PIFOR,TWOPI/1.570796,.785398,6.283185/
C
        IF(ITYM.GT.0)GO TO 10
        P1SQ=P1*P1
        D1SQ=D1*D1
        PSQ=P*P
        DSQ=D*D
        D1SQ3=D1*SQRT3
        D2SQ3=D1SQ*SQRT3
        IF(NP.EQ.0)GO TO 2000
        IF(NP.EQ.1)GO TO 3000
        IF(NP.NE.7)GO TO 60
        IF(P1.GT.(P+D1*(SQRT3-1))) GO TO 60
        IF(D.GE.D1*(SQRT3+1.)-P)GO TO 130
     60 WRITE(6,90)
     90 FORMAT(1X,'UNACCEPTABLE GRANULATION')
        STOP
    130 W=D1-P
        IF(W.LT.0)GO TO 60
        W0=(D-P-2.*D1)/2.
        IF(W0.LT.0.)GO TO 60
        W1=(2.*D1-P-P1)/2.
        IF(W1.LT.0.)GO TO 60
        X1=(P1SQ-PSQ+4.*D1SQ-2.*P1*D1SQ3)/4./(D1SQ3+P-P1)
        X2=(4.*D1SQ+D*D-2.*D*D1SQ3-PSQ)/4./(-D1SQ3+P+D)
        A=PI*L*(D+P1+6.*P)+HAFPI*(D[illegible]P1SQ-6.*PSQ)
        U=PI*L/4.*(DSQ-P1SQ-6.*PSQ)
        W4=AMIN1(W,W0,W1)
     10 MASSF=0.
        TWOX=X+X
        XSQ=X*X
        P1P2X=P1+TWOX
        PP2X=P+TWOX
        DM2X=D-TWOX
        LM2X=L-TWOX
        P12XSQ=P1P2X*P1P2X
        PP2XSQ=PP2X*PP2X
        DM2XSQ=DM2X*DM2X
        IF(NP.EQ.0)GO TO 2000
        IF(NP.EQ.1)GO TO 3000
        IF(LM2X.GT.0)GO TO 340
```

```
      SURF=0.
      V=0.
      GO TO 850
340   S0=PI*LM2X*(D+P1+6.*P+12.*X)+HAFPI*(DM2X*DM2X
     1 -P1P2X*P1P2X-6.*PP2X*PP2X)
      V0=PIFOR*LM2X*(DM2X*DM2X-P1P2X*P1P2X-6.*PP2X*PP2X)
      IF(X.GT.W4/2.)GO TO 360
      MASSF=-TWOX/L/(DSQ-P1SQ-6.*PSQ)
      MASSF=MASSF*(24.*XSQ+(24.*P+4.*P1+4.*D-12.*L)*X+P1SQ
     1 +6.*PSQ-2.*L*D-2.*P1*L-12.*L*P-DSQ)
      SURF=S0
      RETURN
360   IF(X.GT.W1/2.)GO TO 390
      F2=0.
      L2=0.
      A3=0.
      A4=0.
      GO TO 460
390   Z=(2.*D1+P+P1+4.*X)/4.
      B3=((P1-P)*(P1+P+4.*X)+4.*D1SQ)/4./D1/P1P2X
      A3=ATAN(SQRT(1.-B3*B3)/B3)
      B4=((P-P1)*(P+P1+4.*X)+4.*D1SQ)/4./D1/PP2X
      A4=ATAN(SQRT(1.-B4*B4)/B4)
      F2=A3/4.*P12XSQ+A4/4.*PP2XSQ
     1 -SQRT(Z*(Z-D1)*(2.*Z-P-TWOX)*(2.*Z-P1-TWOX))
      L2=LM2X*(A4*PP2X+A3*P1P2X)
460   IF(X.GT.W/2.)GO TO 490
      F3=0.
      L3=0.
      A5=0.
      GO TO 530
490   B5=D1/PP2X
      A5=ATAN(SQRT(1.-B5*B5)/B5)
      F3=(A5*PP2XSQ-D1*SQRT(PP2XSQ-D1SQ))/2.
      L3=2.*A5*LM2X*PP2X
530   IF(X.GT.W0/2.)GO TO 560
      F1=0.
      L1=0.
      A1=0.
      A2=0.
      GO TO 650
560   Y=(2.*D1+P+D)/4.
      B1=((D+P)*(D-P-4.*X)-4.*D1SQ)/4./D1/PP2X
      A1=ATAN(SQRT(1.-B1*B1)/B1)
      IF(A1.GT.0.)GO TO 610
      A1=PI+A1
610   B2=((D+P)*(D-P-4.*X)+4.*D1SQ)/4./D1/DM2X
      A2=ATAN(SQRT(1.-B2*B2)/B2)
      F1=A1/4.*PP2XSQ-A2/4.*DM2XSQ+SQRT(Y*(Y-D1)
     1 *(2.*Y-P-TWOX)*(2.*Y-D+TWOX))
      L1=LM2X*(A1*PP2X+A2*DM2X)
650   IF(X.GT.W/2.)GO TO 690
      SURF=S0+12.*(F1+F2+F3)-6.*(L1+L2+L3)
      V=V0+6.*(F1+F2+F3)*LM2X
      GO TO 850
```

```
  690 IF(X.LT.X1)GO TO 730
      S1=0.0
      V1=0.0
      GO TO 760
  730 S1=3.*D2SQ3-PI*PP2XSQ-HAFPI*P12XSQ
     $ +6.*F3+12.*F2
      S1=S1+LM2X*(2.*(PI-3.*A5-3.*A4)*PP2X+(PI-6.*A3)
     $ *P1P2X)
      V1=LM2X/2.*(3.*D2SQ3-PI*PP2XSQ
     $ -HAFPI*P12XSQ+6.*F3+12.*F2)
  760 IF(X.LT.X2) GO TO 800
      S2=0.0
      V2=0.0
      GO TO 830
  800 S2=HAFPI*DM2XSQ-3.*D2SQ3-TWOPI*PP2XSQ
     $ +12.*F1+6.*F3
      S2=S2+LM2X*((PI-6.*A2)*DM2X+2.*(TWOPI-3.*A1-3.*A5)
     $ *PP2X)
      V2=LM2X/2.*(HAFPI*DM2XSQ-3.*D2SQ3-TWOPI
     $ *PP2XSQ+12.*F1+6.*F3)
  830 SURF=S1+S2
      V=V1+V2
  850 MASSF=1.-V/U
      RETURN
C
C ZERO PERF CALCULATIONS START HERE.
C
 2000 if(d-2*x.le.0.0) go to 2001
      twox=x+x
      xsq=x*x
      MASSF=TWOX*(DSQ+2.*L*D-4.*X*D-TWOX*L+4.*XSQ)/(DSQ*L)
      u=dsq*l*pi/4.
      SURF=PI*(DSQ/2.-4.*D*X-TWOX*L+D*L+6.*XSQ)
      RETURN
2001  surf=0.0
      massf=1.0
      u=dsq*l*pi/4.
      return
C
C ONE PERF CALCULATIONS START HERE.
C
 3000 if(d-p-4.*x.le.0.0) goto 3001
      twox=x+x
      MASSF=TWOX*(DSQ+2.*L*D-4.*X*D-PSQ+2.*P*L-4.*P*X)
     $ /(DSQ*L-PSQ*L)
      u=dsq*l*pi/4.-psq*l*pi/4.
      SURF=PI*(DSQ/2.-4.*D*X-4.*X*P+D*L+P*L-PSQ/2.)
      RETURN
3001  surf=0.0
      massf=1.0
      u=dsq*l*pi/4.-psq*l*pi/4.
      return
      END
```

APPENDIX C

USER'S MANUAL FOR IBRGA

IBRGA relies on an input data base consisting of all numerical parameters essential for running the code. All values are in metric units. Below is a compilation of a typical IBRGAC data base showing the name and location of each input parameter. The names for the numerical values are prefixed with an alphabetical designator corresponding to the position at which the data is to appear, that is, from left to right. The data may be separated by blanks or commas. The units are shown to the right of each input.

A B C D E F G H I J K

record 1

A. - chamber volume (cm^3)
B. - groove diameter (cm)
C. - land diameter (cm)
D. - groove/land ratio (none)
E. - twist (turns/caliber)
F. - projectile travel (cm)
G. - gradient switch (1 = Lagrange, 2 = chambrage)

record 1a (Read only if gradient switch = 2)

A. - number of points to describe chamber ($I \leq 10$)
B. - initial distance from breech (must be 0.0 cm)
C. - diameter at 0 (cm)

.
.
.

Ith distance from breech (position of base of projectile (cm))
Ith diameter at Ith distance (used to calculate bore area).(cm)

record 2

A. - projectile mass (kg)
B. - switch to calculate energy lost to air resistance
C. - fraction of work done against bore to heat tube
D. - gas pressure in front of projectile (Pa)

record 3

A. - number of barrel resistance points ($J \leq 10$)
B. - bore resistance (MPa)
C. - travel (cm)

.
.
.

Jth bore resistance (MPa)
Jth travel (cm)

record 4

A. - mass of recoiling parts (kg)
B. - number of recoil point pairs (2)
C. - recoil force (N)
D. - recoil time (s)
E. - recoil force (N)
F. - recoil time (s)

record 5

A. - free convective heat transfer coefficient (W/cm^2)
B. - chamber wall thickness (cm)
C. - heat capacity of steel of chamber wall (J/g-K)
D. - initial temperature of chamber wall (K)
E. - heat loss coefficient
F. - density of chamber wall steel (g/cm^3)

record 6

A. - impetus of igniter propellant (J/g)
B. - covolume of igniter (cm^3/g)
C. - adiabatic flame temperature of igniter propellant (K)
D. - initial mass of igniter (kg)
E. - ratio of specific heats for igniter

record 7

A. - number of propellants ($K \leq 10$)
B. - impetus of propellant (J/g)
C. - adiabatic temperature of propellant (K)
D. - covolume of propellant (cm^3/g)
E. - initial mass of propellant (kg)
F. - density of propellant (g/cm^3)
G. - ratio of specific heats for propellant
H. - number of perforations of propellant (may be 0,1, or 7 only)
I. - length of propellant grain (cm)
J. - diameter of inner perforations in propellant grains (cm)
K. - diameter of outer perforations of propellant grains (cm)
L. - outside diameter of propellant grain (cm)
M. - distance between perf centers (cm)

.

.

.

(Kth propellent)

A. - impetus of propellant (J/g)
B. - adiabatic temperature of propellant (K)
C. - covolume of propellant (cm^3/g)
D. - initial mass of propellant (kg)
E. - density of propellant (gm/cm^3)
F. - ratio of specific heats for propellant
G. - number of perforations of propellant
H. - length of propellant grain (cm)
I. - diameter of inner perforations in propellant grains (cm)
J. - diameter of outer perforations of propellant grains (cm)
K. - outside diameter of propellant grain (cm)
L. - distance between perf centers (cm)

record 8

A. - number of burning rate points ($J \leq 10$) for propellent 1
B. - exponent
C. - coefficient (cm/s-MPa^{α_i})
D. - pressure (MPa)
.
.
.

Jth exponent
Jth coefficient
Jth pressure
.
.
.

A. - number of burning rate points ($L \leq 10$) for propellent N
B. - exponent
C. - coefficient (cm/s-MPa^{α_i})
D. - pressure (MPa)
.
.
.

Lth exponent
Lth coefficient
Lth pressure

record 9

A. - time increment (ms)
B. - print increment (ms)
C - time to stop calculation (ms)

APPENDIX D

Input data base for the bore-diameter calculation.

```
 9832.2384 12.7 12.7 1.0 0.0  457.2 1
 9.796 0 0.0 0.0
5 0.0 0.0 0.0 .6 0.0 1.3 0.0 300. 0. 457.
 1.e20 2 3.0e+4 0.0 8.0e+5 0.2
 0.001135 .01143 .46028 273. 1. 7.8612
 84.5535 .9755 294. .004712 1.4
1 1135.99 3141. .9755 8.7 1.6605 1.23 7 3.175 .0508 .0508 1.07208908 .28072226
1 1.0 .1105187 689.476
0.005 .05 30.
```

APPENDIX D

Output for the bore-diameter calculation.

```
THE INPUT FILE IS iclopt
using Lagrange pressure gradient
chamber vclume cm**3  0.983224E+04
 groove diam cm  0.127000E+02
land diam cm  0.127000E+02
 groove/land ratio  0.100000E+01
 twist turns/caliber   0.000000E+00
 projectile travel cm  0.457200E+03



projectile mass kg  0.979600E+01
 switch to calculate energy lost to air resistance J 0
 fraction of work against bore used to heat the tube  0.000000E+00
 gas pressure Pa  0.000000E+00
number barrel resistance points 5
 bore resistance MPa - travel cm
  0.000000E+00  0.000000E+00
  0.000000E+00  0.600000E+00
  0.000000E+00  0.130000E+01
  0.000000E+00  0.300000E+03
  0.000000E+00  0.457000E+03

  mass of recoiling parts kg  0.100000E+21
 number of recoil point pairs 2
 recoil force N  recoil time sec
  0.300000E+05     0.000000E+00
  0.800000E+06     0.200000E+00

  free convective heat transfer coefficient w/cm**2 K  0.113500E-02
 chamber wall thickness cm  0.114300E-01
 heat capacity of steel of chamber wall J/g K  0.460280E+00
 initial temperature of chamber wall K  0.273000E+03
 heat loss coefficient  0.100000E+01
 density of chamber wall steel g/cm**3  0.786120E+01


  impetus of igniter propellant J/g  0.845535E+02
 covolume of igniter cm**3/g  0.975500E+00
 adiabatic flame temperature of igniter propellant K  0.294000E+03
 initial mass of igniter kg  0.471200E-02
ratio of specific heats for igniter  0.140000E+01


for propellant number 1
 impetus of propellant J/g   0.113599E+04
 adiabatic temperature of propellant K  0.314100E+04
 covolume of propellant cm**3/g  0.975500E+00
 initial mass of propellant kg  0.870000E+01
 density of propellant g/cm**3  0.166050E+01
 ratio of specific heats for propellant  0.123000E+01
```

number of perforations of propellant 7
length of propellant grain cm 0.317500E+01
diameter of inner perforation in propellant grains cm 0.508000E-01
diameter of outerperforation of propellant grains cm 0.508000E-01
outside diameter of propellant grain cm 0.107209E+01
distance between perf centers cm 0.280722E+00

number of burning rate points 1

exponent	coefficient	pressure
-	cm/sec-MPa**ai	MPa
0.100000E+01	0.110519E+00	0.689476E+03

time increment msec 0.500000E-02 print increment msec 0.500000E-01
time to stop calculation msec 0.300000E+02
area bore m^2 0.126677E-01 pressure from ign Pa 0.868339E+05
volume of unburnt prop m^3 0.523939E-02
init cham vol-cov ign m ^3 0.982764E-02

time	acc	vel	dis	mpress	pbase	pbrch
0.5000E-05	0.8761E+02	0.4356E-03	0.1087E-08	0.8782E+05	0.6775E+05	0.9785E+05
0.5000E-04	0.9693E+02	0.4585E-02	0.1125E-06	0.9716E+05	0.7496E+05	0.1083E+06
0.1050E-03	0.1095E+03	0.1026E-01	0.5174E-06	0.1098E+06	0.8471E+05	0.1223E+06
0.1550E-03	0.1223E+03	0.1605E-01	0.1172E-05	0.1226E+06	0.9456E+05	0.1366E+06
0.2000E-03	0.1349E+03	0.2183E-01	0.2022E-05	0.1352E+06	0.1043E+06	0.1506E+06
0.2500E-03	0.1502E+03	0.2895E-01	0.3289E-05	0.1505E+06	0.1161E+06	0.1677E+06
0.3050E-03	0.1687E+03	0.3771E-01	0.5117E-05	0.1691E+06	0.1305E+06	0.1885E+06
0.3550E-03	0.1873E+03	0.4660E-01	0.7221E-05	0.1878E+06	0.1449E+06	0.2092E+06
0.4050E-03	0.2077E+03	0.5647E-01	0.9793E-05	0.2081E+06	0.1606E+06	0.2319E+06
0.4550E-03	0.2298E+03	0.6740E-01	0.1289E-04	0.2304E+06	0.1777E+06	0.2567E+06
0.5050E-03	0.2539E+03	0.7949E-01	0.1655E-04	0.2545E+06	0.1964E+06	0.2836E+06
0.5550E-03	0.2801E+03	0.9283E-01	0.2086E-04	0.2807E+06	0.2166E+06	0.3128E+06
0.6000E-03	0.3055E+03	0.1060E+00	0.2532E-04	0.3062E+06	0.2362E+06	0.3412E+06
0.6500E-03	0.3358E+03	0.1220E+00	0.3102E-04	0.3366E+06	0.2597E+06	0.3751E+06
0.7000E-03	0.3686E+03	0.1396E+00	0.3755E-04	0.3695E+06	0.2850E+06	0.4117E+06
0.7500E-03	0.4039E+03	0.1589E+00	0.4501E-04	0.4048E+06	0.3123E+06	0.4511E+06
0.8000E-03	0.4417E+03	0.1800E+00	0.5347E-04	0.4428E+06	0.3416E+06	0.4934E+06
0.8500E-03	0.4824E+03	0.2031E+00	0.6305E-04	0.4835E+06	0.3730E+06	0.5388E+06
0.9000E-03	0.5260E+03	0.2283E+00	0.7382E-04	0.5272E+06	0.4067E+06	0.5874E+06
0.9500E-03	0.5726E+03	0.2558E+00	0.8592E-04	0.5739E+06	0.4428E+06	0.6395E+06
0.1000E-02	0.6224E+03	0.2856E+00	0.9944E-04	0.6239E+06	0.4813E+06	0.6951E+06
0.1050E-02	0.6756E+03	0.3181E+00	0.1145E-03	0.6772E+06	0.5225E+06	0.7546E+06
0.1100E-02	0.7324E+03	0.3533E+00	0.1313E-03	0.7341E+06	0.5664E+06	0.8180E+06
0.1150E-02	0.7930E+03	0.3914E+00	0.1499E-03	0.7949E+06	0.6132E+06	0.8857E+06
0.1200E-02	0.8576E+03	0.4326E+00	0.1705E-03	0.8596E+06	0.6632E+06	0.9579E+06
0.1250E-02	0.9265E+03	0.4772E+00	0.1932E-03	0.9287E+06	0.7165E+06	0.1035E+07
0.1300E-02	0.9999E+03	0.5254E+00	0.2183E-03	0.1002E+07	0.7733E+06	0.1117E+07
0.1350E-02	0.1078E+04	0.5773E+00	0.2458E-03	0.1081E+07	0.8338E+06	0.1204E+07
0.1400E-02	0.1162E+04	0.6333E+00	0.2761E-03	0.1164E+07	0.8983E+06	0.1297E+07
0.1450E-02	0.1251E+04	0.6935E+00	0.3092E-03	0.1253E+07	0.9670E+06	0.1397E+07
0.1500E-02	0.1345E+04	0.7584E+00	0.3455E-03	0.1348E+07	0.1040E+07	0.1503E+07
0.1550E-02	0.1446E+04	0.8282E+00	0.3851E-03	0.1450E+07	0.1119E+07	0.1615E+07
0.1600E-02	0.1554E+04	0.9032E+00	0.4284E-03	0.1558E+07	0.1202E+07	0.1736E+07
0.1650E-02	0.1669E+04	0.9837E+00	0.4755E-03	0.1673E+07	0.1291E+07	0.1864E+07
0.1700E-02	0.1792E+04	0.1070E+01	0.5269E-03	0.1796E+07	0.1386E+07	0.2001E+07
0.1750E-02	0.1923E+04	0.1163E+01	0.5827E-03	0.1927E+07	0.1487E+07	0.2147E+07

0.1800E-02	0.2062E+04	0.1263E+01	0.6433E-03	0.2067E+07	0.1595E+07	0.2303E+07
0.1850E-02	0.2211E+04	0.1369E+01	0.7091E-03	0.2216E+07	0.1710E+07	0.2470E+07
0.1900E-02	0.2370E+04	0.1484E+01	0.7804E-03	0.2376E+07	0.1833E+07	0.2647E+07
0.1950E-02	0.2540E+04	0.1607E+01	0.8576E-03	0.2546E+07	0.1964E+07	0.2837E+07
0.2000E-02	0.2721E+04	0.1738E+01	0.9412E-03	0.2728E+07	0.2104E+07	0.3039E+07
0.2050E-02	0.2915E+04	0.1879E+01	0.1032E-02	0.2922E+07	0.2254E+07	0.3256E+07
0.2100E-02	0.3122E+04	0.2030E+01	0.1129E-02	0.3129E+07	0.2414E+07	0.3486E+07
0.2150E-02	0.3342E+04	0.2191E+01	0.1235E-02	0.3350E+07	0.2585E+07	0.3733E+07
0.2200E-02	0.3578E+04	0.2364E+01	0.1349E-02	0.3587E+07	0.2767E+07	0.3996E+07
0.2255E-02	0.3856E+04	0.2569E+01	0.1484E-02	0.3865E+07	0.2982E+07	0.4307E+07
0.2305E-02	0.4127E+04	0.2768E+01	0.1617E-02	0.4137E+07	0.3191E+07	0.4609E+07
0.2355E-02	0.4416E+04	0.2982E+01	0.1761E-02	0.4426E+07	0.3415E+07	0.4932E+07
0.2405E-02	0.4725E+04	0.3210E+01	0.1916E-02	0.4736E+07	0.3654E+07	0.5277E+07
0.2455E-02	0.5055E+04	0.3454E+01	0.2082E-02	0.5067E+07	0.3909E+07	0.5646E+07
0.2505E-02	0.5407E+04	0.3716E+01	0.2262E-02	0.5420E+07	0.4181E+07	0.6039E+07
0.2555E-02	0.5783E+04	0.3996E+01	0.2454E-02	0.5797E+07	0.4472E+07	0.6459E+07
0.2605E-02	0.6185E+04	0.4295E+01	0.2662E-02	0.6200E+07	0.4783E+07	0.6908E+07
0.2655E-02	0.6614E+04	0.4615E+01	0.2884E-02	0.6630E+07	0.5115E+07	0.7387E+07
0.2705E-02	0.7072E+04	0.4957E+01	0.3123E-02	0.7089E+07	0.5469E+07	0.7899E+07
0.2755E-02	0.7561E+04	0.5322E+01	0.3380E-02	0.7579E+07	0.5847E+07	0.8445E+07
0.2805E-02	0.8083E+04	0.5713E+01	0.3656E-02	0.8102E+07	0.6251E+07	0.9028E+07
0.2855E-02	0.8640E+04	0.6131E+01	0.3952E-02	0.8661E+07	0.6682E+07	0.9650E+07
0.2905E-02	0.9235E+04	0.6578E+01	0.4270E-02	0.9257E+07	0.7141E+07	0.1031E+08
0.2955E-02	0.9869E+04	0.7055E+01	0.4610E-02	0.9893E+07	0.7632E+07	0.1102E+08
0.3005E-02	0.1055E+05	0.7566E+01	0.4976E-02	0.1057E+08	0.8155E+07	0.1178E+08
0.3055E-02	0.1127E+05	0.8111E+01	0.5367E-02	0.1129E+08	0.8714E+07	0.1258E+08
0.3105E-02	0.1204E+05	0.8693E+01	0.5787E-02	0.1207E+08	0.9309E+07	0.1344E+08
0.3155E-02	0.1286E+05	0.9315E+01	0.6237E-02	0.1289E+08	0.9943E+07	0.1436E+08
0.3205E-02	0.1373E+05	0.9980E+01	0.6720E-02	0.1377E+08	0.1062E+08	0.1534E+08
0.3255E-02	0.1466E+05	0.1069E+02	0.7236E-02	0.1470E+08	0.1134E+08	0.1638E+08
0.3305E-02	0.1566E+05	0.1145E+02	0.7789E-02	0.1569E+08	0.1211E+08	0.1749E+08
0.3355E-02	0.1672E+05	0.1226E+02	0.8382E-02	0.1675E+08	0.1293E+08	0.1867E+08
0.3405E-02	0.1784E+05	0.1312E+02	0.9016E-02	0.1788E+08	0.1380E+08	0.1993E+08
0.3455E-02	0.1904E+05	0.1404E+02	0.9695E-02	0.1908E+08	0.1472E+08	0.2126E+08
0.3505E-02	0.2031E+05	0.1503E+02	0.1042E-01	0.2036E+08	0.1571E+08	0.2269E+08
0.3555E-02	0.2167E+05	0.1607E+02	0.1120E-01	0.2172E+08	0.1676E+08	0.2420E+08
0.3605E-02	0.2311E+05	0.1719E+02	0.1203E-01	0.2316E+08	0.1787E+08	0.2581E+08
0.3655E-02	0.2464E+05	0.1839E+02	0.1292E-01	0.2470E+08	0.1905E+08	0.2752E+08
0.3705E-02	0.2627E+05	0.1966E+02	0.1387E-01	0.2633E+08	0.2031E+08	0.2934E+08
0.3755E-02	0.2799E+05	0.2102E+02	0.1489E-01	0.2806E+08	0.2165E+08	0.3126E+08
0.3805E-02	0.2982E+05	0.2246E+02	0.1597E-01	0.2989E+08	0.2306E+08	0.3331E+08
0.3855E-02	0.3177E+05	0.2400E+02	0.1713E-01	0.3184E+08	0.2456E+08	0.3548E+08
0.3905E-02	0.3382E+05	0.2564E+02	0.1837E-01	0.3390E+08	0.2616E+08	0.3778E+08
0.3955E-02	0.3600E+05	0.2738E+02	0.1970E-01	0.3609E+08	0.2784E+08	0.4021E+08
0.4005E-02	0.3831E+05	0.2924E+02	0.2111E-01	0.3840E+08	0.2962E+08	0.4278E+08
0.4055E-02	0.4075E+05	0.3122E+02	0.2263E-01	0.4084E+08	0.3151E+08	0.4551E+08
0.4105E-02	0.4332E+05	0.3332E+02	0.2424E-01	0.4342E+08	0.3350E+08	0.4839E+08
0.4155E-02	0.4604E+05	0.3555E+02	0.2596E-01	0.4615E+08	0.3560E+08	0.5142E+08
0.4205E-02	0.4891E+05	0.3792E+02	0.2780E-01	0.4903E+08	0.3782E+08	0.5463E+08
0.4255E-02	0.5193E+05	0.4044E+02	0.2975E-01	0.5206E+08	0.4016E+08	0.5800E+08
0.4305E-02	0.5512E+05	0.4312E+02	0.3184E-01	0.5525E+08	0.4262E+08	0.6156E+08
0.4355E-02	0.5846E+05	0.4596E+02	0.3407E-01	0.5860E+08	0.4521E+08	0.6530E+08
0.4405E-02	0.6198E+05	0.4897E+02	0.3644E-01	0.6213E+08	0.4793E+08	0.6923E+08
0.4455E-02	0.6567E+05	0.5216E+02	0.3897E-01	0.6583E+08	0.5078E+08	0.7335E+08
0.4505E-02	0.6954E+05	0.5554E+02	0.4166E-01	0.6970E+08	0.5378E+08	0.7767E+08

0.4555E-02	0.7359E+05	0.5912E+02	0.4453E-01	0.7376E+08	0.5691E+08	0.8219E+08
0.4605E-02	0.7782E+05	0.6290E+02	0.4758E-01	0.7800E+08	0.6018E+08	0.8692E+08
0.4655E-02	0.8224E+05	0.6690E+02	0.5082E-01	0.8243E+08	0.6359E+08	0.9185E+08
0.4705E-02	0.8684E+05	0.7113E+02	0.5427E-01	0.8704E+08	0.6715E+08	0.9699E+08
0.4755E-02	0.9163E+05	0.7559E+02	0.5794E-01	0.9185E+08	0.7086E+08	0.1023E+09
0.4805E-02	0.9660E+05	0.8029E+02	0.6183E-01	0.9683E+08	0.7470E+08	0.1079E+09
0.4855E-02	0.1018E+06	0.8525E+02	0.6597E-01	0.1020E+09	0.7869E+08	0.1137E+09
0.4905E-02	0.1071E+06	0.9047E+02	0.7036E-01	0.1074E+09	0.8282E+08	0.1196E+09
0.4955E-02	0.1126E+06	0.9597E+02	0.7502E-01	0.1129E+09	0.8709E+08	0.1258E+09
0.5005E-02	0.1183E+06	0.1017E+03	0.7996E-01	0.1186E+09	0.9149E+08	0.1321E+09
0.5050E-02	0.1236E+06	0.1072E+03	0.8466E-01	0.1239E+09	0.9555E+08	0.1380E+09
0.5100E-02	0.1296E+06	0.1135E+03	0.9018E-01	0.1299E+09	0.1002E+09	0.1447E+09
0.5150E-02	0.1357E+06	0.1201E+03	0.9602E-01	0.1360E+09	0.1049E+09	0.1516E+09
0.5200E-02	0.1420E+06	0.1271E+03	0.1022E+00	0.1423E+09	0.1098E+09	0.1586E+09
0.5250E-02	0.1484E+06	0.1343E+03	0.1087E+00	0.1487E+09	0.1147E+09	0.1657E+09
0.5300E-02	0.1549E+06	0.1419E+03	0.1156E+00	0.1552E+09	0.1198E+09	0.1730E+09
0.5350E-02	0.1615E+06	0.1498E+03	0.1229E+00	0.1618E+09	0.1249E+09	0.1803E+09
0.5400E-02	0.1681E+06	0.1581E+03	0.1306E+00	0.1685E+09	0.1300E+09	0.1878E+09
0.5450E-02	0.1749E+06	0.1666E+03	0.1387E+00	0.1753E+09	0.1352E+09	0.1953E+09
0.5500E-02	0.1816E+06	0.1756E+03	0.1473E+00	0.1821E+09	0.1405E+09	0.2029E+09
0.5550E-02	0.1884E+06	0.1848E+03	0.1563E+00	0.1889E+09	0.1457E+09	0.2104E+09
0.5600E-02	0.1952E+06	0.1944E+03	0.1658E+00	0.1957E+09	0.1510E+09	0.2180E+09
0.5650E-02	0.2020E+06	0.2043E+03	0.1757E+00	0.2024E+09	0.1562E+09	0.2256E+09
0.5700E-02	0.2087E+06	0.2146E+03	0.1862E+00	0.2092E+09	0.1614E+09	0.2331E+09
0.5750E-02	0.2153E+06	0.2252E+03	0.1972E+00	0.2158E+09	0.1665E+09	0.2405E+09
0.5800E-02	0.2218E+06	0.2361E+03	0.2087E+00	0.2224E+09	0.1715E+09	0.2478E+09
0.5850E-02	0.2283E+06	0.2474E+03	0.2208E+00	0.2288E+09	0.1765E+09	0.2549E+09
0.5900E-02	0.2345E+06	0.2589E+03	0.2335E+00	0.2351E+09	0.1814E+09	0.2620E+09
0.5950E-02	0.2407E+06	0.2708E+03	0.2467E+00	0.2412E+09	0.1861E+09	0.2688E+09
0.6000E-02	0.2466E+06	0.2830E+03	0.2606E+00	0.2472E+09	0.1907E+09	0.2754E+09
0.6050E-02	0.2523E+06	0.2955E+03	0.2750E+00	0.2529E+09	0.1951E+09	0.2818E+09
0.6100E-02	0.2579E+06	0.3082E+03	0.2901E+00	0.2585E+09	0.1994E+09	0.2880E+09
0.6150E-02	0.2632E+06	0.3213E+03	0.3059E+00	0.2638E+09	0.2035E+09	0.2939E+09
0.6200E-02	0.2682E+06	0.3345E+03	0.3223E+00	0.2688E+09	0.2074E+09	0.2995E+09
0.6250E-02	0.2730E+06	0.3481E+03	0.3393E+00	0.2736E+09	0.2111E+09	0.3049E+09
0.6300E-02	0.2775E+06	0.3618E+03	0.3571E+00	0.2781E+09	0.2146E+09	0.3099E+09
0.6350E-02	0.2817E+06	0.3758E+03	0.3755E+00	0.2824E+09	0.2178E+09	0.3146E+09
0.6400E-02	0.2856E+06	0.3900E+03	0.3947E+00	0.2863E+09	0.2209E+09	0.3190E+09
0.6450E-02	0.2893E+06	0.4044E+03	0.4145E+00	0.2899E+09	0.2237E+09	0.3231E+09
0.6500E-02	0.2926E+06	0.4189E+03	0.4351E+00	0.2933E+09	0.2263E+09	0.3268E+09
0.6550E-02	0.2956E+06	0.4336E+03	0.4564E+00	0.2963E+09	0.2286E+09	0.3302E+09
0.6600E-02	0.2983E+06	0.4485E+03	0.4785E+00	0.299[illegible]E+09	0.2307E+09	0.3332E+09
0.6650E-02	0.3008E+06	0.4635E+03	0.5013E+00	0.3015E+09	0.2326E+09	0.3359E+09
0.6700E-02	0.3029E+06	0.4786E+03	0.5248E+00	0.[illegible]36E+09	0.2342E+09	0.3383E+09
0.6750E-02	0.3047E+06	0.4937E+03	0.5491E+00	0.[illegible]55E+09	0.2357E+09	0.3404E+09
0.6800E-02	0.3063E+06	0.5090E+03	0.5742E+00	0.3070E+09	0.2369E+09	0.3421E+09
0.6850E-02	0.3076E+06	0.5244E+03	0.6000E+00	0.3083E+09	0.2378E+09	0.3435E+09
0.6900E-02	0.3086E+06	0.5398E+03	0.6266E+00	0.3093E+09	0.2386E+09	0.3446E+09
0.6950E-02	0.3093E+06	0.5552E+03	0.6540E+00	0.3100E+09	0.2392E+09	0.3454E+09
0.7000E-02	0.3098E+06	0.5707E+03	0.6821E+00	0.3105E+09	0.2396E+09	0.3460E+09
0.7050E-02	0.3100E+06	0.5862E+03	0.7111E+00	0.3108E+09	0.2397E+09	0.3463E+09
0.7100E-02	0.3100E+06	0.6017E+03	0.7408E+00	0.3108E+09	0.2397E+09	0.3463E+09
0.7150E-02	0.3098E+06	0.6172E+03	0.7712E+00	0.3105E+09	0.2396E+09	0.3460E+09
0.7200E-02	0.3094E+06	0.6327E+03	0.8025E+00	0.3101E+09	0.2393E+09	0.3456E+09
0.7250E-02	0.3088E+06	0.6481E+03	0.8345E+00	0.3095E+09	0.2388E+09	0.3449E+09

0.7300E-02	0.3080E+06	0.6636E+03	0.8673E+00	0.3087E+09	0.2382E+09	0.3440E+09
0.7350E-02	0.3070E+06	0.6789E+03	0.9009E+00	0.3077E+09	0.2374E+09	0.3429E+09
0.7400E-02	0.3058E+06	0.6942E+03	0.9352E+00	0.3066E+09	0.2365E+09	0.3416E+09
0.7450E-02	0.3045E+06	0.7095E+03	0.9703E+00	0.3053E+09	0.2355E+09	0.3401E+09
0.7500E-02	0.3031E+06	0.7247E+03	0.1006E+01	0.3038E+09	0.2344E+09	0.3385E+09
0.7550E-02	0.3015E+06	0.7398E+03	0.1043E+01	0.3022E+09	0.2332E+09	0.3368E+09
0.7600E-02	0.2998E+06	0.7549E+03	0.1080E+01	0.3005E+09	0.2319E+09	0.3349E+09
0.7650E-02	0.2980E+06	0.7698E+03	0.1118E+01	0.2987E+09	0.2305E+09	0.3329E+09
0.7700E-02	0.2961E+06	0.7847E+03	0.1157E+01	0.2968E+09	0.2290E+09	0.3307E+09
0.7750E-02	0.2941E+06	0.7994E+03	0.1197E+01	0.2948E+09	0.2275E+09	0.3285E+09
0.7800E-02	0.2921E+06	0.8141E+03	0.1237E+01	0.2927E+09	0.2259E+09	0.3262E+09
0.7850E-02	0.2899E+06	0.8286E+03	0.1278E+01	0.2906E+09	0.2242E+09	0.3238E+09
0.7900E-02	0.2877E+06	0.8431E+03	0.1320E+01	0.2884E+09	0.2225E+09	0.3213E+09
0.7950E-02	0.2854E+06	0.8574E+03	0.1362E+01	0.2861E+09	0.2207E+09	0.3188E+09
0.8000E-02	0.2831E+06	0.8716E+03	0.1406E+01	0.2837E+09	0.2189E+09	0.3162E+09
0.8050E-02	0.2807E+06	0.8857E+03	0.1450E+01	0.2814E+09	0.2171E+09	0.3135E+09
0.8100E-02	0.2783E+06	0.8997E+03	0.1494E+01	0.2789E+09	0.2152E+09	0.3108E+09
0.8150E-02	0.2758E+06	0.9135E+03	0.1540E+01	0.2765E+09	0.2133E+09	0.3081E+09
0.8200E-02	0.2733E+06	0.9272E+03	0.1586E+01	0.2740E+09	0.2114E+09	0.3053E+09
0.8250E-02	0.2708E+06	0.9408E+03	0.1632E+01	0.2715E+09	0.2094E+09	0.3025E+09
0.8300E-02	0.2683E+06	0.9543E+03	0.1680E+01	0.2689E+09	0.2075E+09	0.2997E+09
0.8350E-02	0.2658E+06	0.9677E+03	0.1728E+01	0.2664E+09	0.2055E+09	0.2968E+09
0.8400E-02	0.2632E+06	0.9809E+03	0.1776E+01	0.2638E+09	0.2036E+09	0.2940E+09
0.8450E-02	0.2607E+06	0.9940E+03	0.1826E+01	0.2613E+09	0.2016E+09	0.2911E+09
0.8500E-02	0.2581E+06	0.1007E+04	0.1876E+01	0.2587E+09	0.1996E+09	0.2883E+09
0.8550E-02	0.2556E+06	0.1020E+04	0.1926E+01	0.2562E+09	0.1976E+09	0.2854E+09
0.8600E-02	0.2530E+06	0.1033E+04	0.1978E+01	0.2536E+09	0.1956E+09	0.2826E+09
0.8650E-02	0.2502E+06	0.1045E+04	0.2030E+01	0.2507E+09	0.1934E+09	0.2794E+09
0.8700E-02	0.2466E+06	0.1058E+04	0.2082E+01	0.2472E+09	0.1907E+09	0.2754E+09
0.8750E-02	0.2428E+06	0.1070E+04	0.2135E+01	0.2433E+09	0.1877E+09	0.2711E+09
0.8800E-02	0.2387E+06	0.1082E+04	0.2189E+01	0.2393E+09	0.1846E+09	0.2666E+09
0.8850E-02	0.2345E+06	0.1094E+04	0.2244E+01	0.2350E+09	0.1813E+09	0.2619E+09
0.8900E-02	0.2302E+06	0.1105E+04	0.2299E+01	0.2308E+09	0.1780E+09	0.2571E+09
0.8950E-02	0.2259E+06	0.1117E+04	0.2354E+01	0.2264E+09	0.1747E+09	0.2523E+09
0.9005E-02	0.2211E+06	0.1129E+04	0.2416E+01	0.2216E+09	0.1710E+09	0.2469E+09
0.9055E-02	0.2167E+06	0.1140E+04	0.2473E+01	0.2173E+09	0.1676E+09	0.2421E+09
0.9105E-02	0.2124E+06	0.1151E+04	0.2530E+01	0.2129E+09	0.1643E+09	0.2372E+09
0.9155E-02	0.2081E+06	0.1161E+04	0.2588E+01	0.2086E+09	0.1609E+09	0.2324E+09
0.9205E-02	0.2039E+06	0.1171E+04	0.2646E+01	0.2043E+09	0.1576E+09	0.2277E+09
0.9255E-02	0.1996E+06	0.1182E+04	0.2705E+01	0.2001E+09	0.1544E+09	0.2230E+09
0.9305E-02	0.1955E+06	0.1191E+04	0.2764E+01	0.1960E+09	0.1512E+09	0.2183E+09
0.9355E-02	0.1914E+06	0.1201E+04	0.2824E+01	0.1919E+09	0.1480E+09	0.2138E+09
0.9405E-02	0.1874E+06	0.1211E+04	0.2884E+01	0.1878E+09	0.1449E+09	0.2093E+09
0.9455E-02	0.1835E+06	0.1220E+04	0.2945E+01	0.1839E+09	0.1419E+09	0.2049E+09
0.9505E-02	0.1796E+06	0.1229E+04	0.3006E+01	0.1800E+09	0.1389E+09	0.2006E+09
0.9555E-02	0.1758E+06	0.1238E+04	0.3068E+01	0.1762E+09	0.1360E+09	0.1964E+09
0.9605E-02	0.1721E+06	0.1246E+04	0.3130E+01	0.1725E+09	0.1331E+09	0.1923E+09
0.9655E-02	0.1685E+06	0.1255E+04	0.3193E+01	0.1689E+09	0.1303E+09	0.1882E+09
0.9705E-02	0.1650E+06	0.1263E+04	0.3256E+01	0.1654E+09	0.1276E+09	0.1843E+09
0.9755E-02	0.1616E+06	0.1271E+04	0.3319E+01	0.1620E+09	0.1250E+09	0.1805E+09
0.9805E-02	0.1583E+06	0.1279E+04	0.3383E+01	0.1587E+09	0.1224E+09	0.1768E+09
0.9855E-02	0.1551E+06	0.1287E+04	0.3447E+01	0.1555E+09	0.1199E+09	0.1732E+09
0.9905E-02	0.1519E+06	0.1295E+04	0.3511E+01	0.1523E+09	0.1175E+09	0.1697E+09
0.9955E-02	0.1489E+06	0.1303E+04	0.3576E+01	0.1492E+09	0.1151E+09	0.1663E+09
0.1000E-01	0.1459E+06	0.1310E+04	0.3642E+01	0.1462E+09	0.1128E+09	0.1630E+09

0.1005E-01	0.1430E+06	0.1317E+04	0.3707E+01	0.1433E+09	0.1106E+09	0.1597E+09
0.1010E-01	0.1402E+06	0.1324E+04	0.3773E+01	0.1405E+09	0.1084E+09	0.1566E+09
0.1015E-01	0.1374E+06	0.1331E+04	0.3840E+01	0.1377E+09	0.1063E+09	0.1535E+09
0.1020E-01	0.1347E+06	0.1338E+04	0.3906E+01	0.1351E+09	0.1042E+09	0.1505E+09
0.1025E-01	0.1321E+06	0.1345E+04	0.3974E+01	0.1325E+09	0.1022E+09	0.1476E+09
0.1030E-01	0.1296E+06	0.1351E+04	0.4041E+01	0.1299E+09	0.1002E+09	0.1448E+09
0.1035E-01	0.1271E+06	0.1358E+04	0.4109E+01	0.1274E+09	0.9832E+08	0.1420E+09
0.1040E-01	0.1247E+06	0.1364E+04	0.4177E+01	0.1250E+09	0.9646E+08	0.1393E+09
0.1045E-01	0.1224E+06	0.1370E+04	0.4245E+01	0.1227E+09	0.9466E+08	0.1367E+09
0.1050E-01	0.1201E+06	0.1376E+04	0.4314E+01	0.1204E+09	0.9289E+08	0.1342E+09
0.1055E-01	0.1179E+06	0.1382E+04	0.4383E+01	0.1182E+09	0.9118E+08	0.1317E+09
0.1060E-01	0.1158E+06	0.1388E+04	0.4452E+01	0.1160E+09	0.8951E+08	0.1293E+09
0.1065E-01	0.1136E+06	0.1394E+04	0.4521E+01	0.1139E+09	0.8788E+08	0.1269E+09

deltat t 0.106950E-01 intg t 0.106948E-01

PMAXMEAN Pa 0.310784E+09 time at PMAXMEAN sec 0.707511E-02

PMAXBASE Pa 0.239766E+09 time at PMAXBASE sec 0.707511E-02

PMAXBREECH Pa 0.346294E+09 time at PMAXBREECH sec 0.707511E-02

muzzle VELOCITY m/s 0.139773E+04 time of muzzle velocity sec 0.106910E-01

total initial energy available J = 0.429710E+08

FOR PROPELLANT 1 MASSFRACT BURNT IS 0.996610E+00

total energy remaining in gas J= 0.289575E+08

energy loss from projectile translation J= 0.957471E+07

energy loss from projectile rotation J= 0.000000E+00

energy lost to gas and propellant motion J= 0.283602E+07

energy lost to bore resistance J= 0.000000E+00

energy lost to recoil J= 0.187099E-11

energy loss from heat transfer J= 0.145715E+07

energy lost to air resistance J= 0.000000E+00

APPENDIX E

Input data base for the chambrage calculation.

```
  9832.2384 12.7 12.7 1.0 0.0  457.2 2
3 0. 15.39110755 46.4820 15.39110755 54.1020 12.70
  9.796 0. 0.0 0.0
5 0.0 0.0 0.0 .6 0.0 1.3 0.0 300. 0. 457.
  1.e20 2 3.0e+4 0.0 8.0e+5 0.2
  .001135 .01143 .46028 273. 1. 7.8612
  84.5535 .9755 294. .004712 1.4
1 1135.99 3141. .9755 8.85 1.6605 1.23 7 3.175 .0508 .0508 1.06290007 .27842504
 1 1.0 .1105187 689.476
 .005 .05 30.
```

APPENDIX E

Output for the chambrage chamber calculation.

```
THE INPUT FILE IS iclch2
Using chambrage pressure gradient

   chamber distance cm   chamber diameter cm
       0.000000E+00         0.153911E+02
       0.464820E+02         0.153911E+02
       0.541020E+02         0.127000E+02
chamber volume cm**3  0.983215E+04
 groove diam cm  0.127000E+02
land diam cm  0.127000E+02
 groove/land ratio  0.100000E+01
 twist turns/caliber   0.000000E+00
 projectile travel cm  0.457200E+03


projectile mass kg  0.979600E+01
 switch to calculate energy lost to air resistance J 0
 fraction of work against bore used to heat the tube  0.000000E+00
 gas pressure Pa  0.000000E+00
number barrel resistance points 5
 bore resistance MPa - travel cm
  0.000000E+00  0.000000E+00
  0.000000E+00  0.600000E+00
  0.000000E+00  0.130000E+01
  0.000000E+00  0.300000E+03
  0.000000E+00  0.457000E+03

  mass of recoiling parts kg  0.100000E+21
 number of recoil point pairs 2
 recoil force N  recoil time sec
  0.300000E+05     0.000000E+00
  0.800000E+06     0.200000E+00

  free convective heat transfer coefficient w/cm**2 K  0.113500E-02
 chamber wall thickness cm  0.114300E-01
 heat capacity of steel of chamber wall J/g K  0.460280E+00
 initial temperature of chamber wall K  0.273000E+03
 heat loss coefficient  0.100000E+01
 density of chamber wall steel g/cm**3  0.786120E+01


  impetus of igniter propellant J/g  0.845535E+02
 covolume of igniter cm**3/g  0.975500E+00
 adiabatic flame temperature of igniter propellant K  0.294000E+03
 initial mass of igniter kg  0.471200E-02
ratio of specific heats for igniter  0.140000E+01


for propellant number 1
 impetus of propellant J/g   0.113599E+04
```

adiabatic temperature of propellant K 0.314100E+04
covolume of propellant cm**3/g 0.975500E+00
initial mass of propellant kg 0.885000E+01
density of propellant g/cm**3 0.166050E+01
ratio of specific heats for propellant 0.123000E+01
number of perforations of propellant 7
length of propellant grain cm 0.317500E+01
diameter of inner perforation in propellant grains cm 0.508000E-01
diameter of outerperforation of propellant grains cm 0.508000E-01
outside diameter of propellant grain cm 0.106290E+01
distance between perf centers cm 0.278425E+00

number of burning rate points 1

exponent	coefficient	pressure
-	cm/sec-MPa**ai	MPa
0.100000E+01	0.110519E+00	0.689476E+03

time increment msec 0.500000E-02 print increment msec 0.500000E-01
time to stop calculation msec 0.300000E+02
area bore m^2 0.126677E-01 pressure from ign Pa 0.885796E+05
volume of unburnt prop m^3 0.532972E-02
init cham vol-cov ign m ^3 0.982755E-02

time	acc	vel	dis	mpress	pbase	pbrch
0.5000E-05	0.9985E+02	0.4141E-03	0.8272E-09	0.8963E+05	0.7721E+05	0.9509E+05
0.5000E-04	0.1110E+03	0.5154E-02	0.1242E-06	0.9964E+05	0.8584E+05	0.1057E+06
0.1050E-03	0.1262E+03	0.1167E-01	0.5830E-06	0.1133E+06	0.9757E+05	0.1202E+06
0.1550E-03	0.1416E+03	0.1835E-01	0.1330E-05	0.1271E+06	0.1095E+06	0.1348E+06
0.2000E-03	0.1568E+03	0.2506E-01	0.2305E-05	0.1408E+06	0.1213E+06	0.1493E+06
0.2500E-03	0.1755E+03	0.3336E-01	0.3761E-05	0.1575E+06	0.1357E+06	0.1671E+06
0.3050E-03	0.1982E+03	0.4363E-01	0.5873E-05	0.1779E+06	0.1533E+06	0.1888E+06
0.3550E-03	0.2210E+03	0.5410E-01	0.8311E-05	0.1984E+06	0.1709E+06	0.2105E+06
0.4050E-03	0.2461E+03	0.6577E-01	0.1130E-04	0.2209E+06	0.1903E+06	0.2343E+06
0.4550E-03	0.2735E+03	0.7875E-01	0.1491E-04	0.2455E+06	0.2115E+06	0.2604E+06
0.5050E-03	0.3033E+03	0.9315E-01	0.1920E-04	0.2723E+06	0.2346E+06	0.2889E+06
0.5550E-03	0.3359E+03	0.1091E+00	0.2425E-04	0.3015E+06	0.2597E+06	0.3199E+06
0.6000E-03	0.3675E+03	0.1249E+00	0.2951E-04	0.3299E+06	0.2842E+06	0.3500E+06
0.6500E-03	0.4054E+03	0.1443E+00	0.3623E-04	0.3640E+06	0.3135E+06	0.3861E+06
0.7000E-03	0.4465E+03	0.1655E+00	0.4397E-04	0.4008E+06	0.3452E+06	0.4252E+06
0.7500E-03	0.4907E+03	0.1889E+00	0.5282E-04	0.4405E+06	0.3795E+06	0.4673E+06
0.8000E-03	0.5384E+03	0.2147E+00	0.6290E-04	0.4833E+06	0.4163E+06	0.5127E+06
0.8500E-03	0.5896E+03	0.2428E+00	0.7433E-04	0.5293E+06	0.4559E+06	0.5615E+06
0.9000E-03	0.6446E+03	0.2737E+00	0.8723E-04	0.5787E+06	0.4985E+06	0.6140E+06
0.9500E-03	0.7036E+03	0.3074E+00	0.1017E-03	0.6317E+06	0.5441E+06	0.6702E+06
0.1000E-02	0.7669E+03	0.3441E+00	0.1180E-03	0.6885E+06	0.5930E+06	0.7304E+06
0.1050E-02	0.8346E+03	0.3841E+00	0.1362E-03	0.7493E+06	0.6454E+06	0.7949E+06
0.1100E-02	0.9070E+03	0.4277E+00	0.1565E-03	0.8143E+06	0.7014E+06	0.8639E+06
0.1150E-02	0.9845E+03	0.4749E+00	0.1790E-03	0.8839E+06	0.7613E+06	0.9377E+06
0.1200E-02	0.1067E+04	0.5262E+00	0.2041E-03	0.9583E+06	0.8254E+06	0.1017E+07
0.1250E-02	0.1156E+04	0.5818E+00	0.2317E-03	0.1038E+07	0.8939E+06	0.1101E+07
0.1300E-02	0.1251E+04	0.6419E+00	0.2623E-03	0.1123E+07	0.9671E+06	0.1191E+07
0.1350E-02	0.1352E+04	0.7069E+00	0.2960E-03	0.1214E+07	0.1045E+07	0.1288E+07
0.1400E-02	0.1460E+04	0.7772E+00	0.3331E-03	0.1311E+07	0.1129E+07	0.1391E+07
0.1450E-02	0.1576E+04	0.8531E+00	0.3738E-03	0.1415E+07	0.1219E+07	0.1501E+07
0.1500E-02	0.1700E+04	0.9349E+00	0.4185E-03	0.1526E+07	0.1314E+07	0.1619E+07

0.1550E-02	0.1832E+04	0.1023E+01	0.4674E-03	0.1645E+07	0.1417E+07	0.1745E+07
0.1600E-02	0.1974E+04	0.1118E+01	0.5209E-03	0.1772E+07	0.1526E+07	0.1880E+07
0.1650E-02	0.2125E+04	0.1221E+01	0.5794E-03	0.1909E+07	0.1643E+07	0.2025E+07
0.1700E-02	0.2287E+04	0.1331E+01	0.6431E-03	0.2054E+07	0.1769E+07	0.2179E+07
0.1750E-02	0.2461E+04	0.1450E+01	0.7126E-03	0.2210E+07	0.1903E+07	0.2345E+07
0.1800E-02	0.2647E+04	0.1577E+01	0.7882E-03	0.2377E+07	0.2047E+07	0.2522E+07
0.1850E-02	0.2846E+04	0.1715E+01	0.8705E-03	0.2556E+07	0.2201E+07	0.2712E+07
0.1900E-02	0.3059E+04	0.1862E+01	0.9598E-03	0.2748E+07	0.2365E+07	0.2915E+07
0.1950E-02	0.3287E+04	0.2021E+01	0.1057E-02	0.2953E+07	0.2542E+07	0.3133E+07
0.2000E-02	0.3531E+04	0.2191E+01	0.1162E-02	0.3173E+07	0.2731E+07	0.3366E+07
0.2050E-02	0.3793E+04	0.2374E+01	0.1276E-02	0.3408E+07	0.2933E+07	0.3616E+07
0.2100E-02	0.4074E+04	0.2571E+01	0.1400E-02	0.3661E+07	0.3150E+07	0.3883E+07
0.2150E-02	0.4374E+04	0.2782E+01	0.1533E-02	0.3931E+07	0.3382E+07	0.4170E+07
0.2200E-02	0.4696E+04	0.3008E+01	0.1678E-02	0.4220E+07	0.3631E+07	0.4477E+07
0.2255E-02	0.5076E+04	0.3277E+01	0.1851E-02	0.4563E+07	0.3925E+07	0.4840E+07
0.2305E-02	0.5447E+04	0.3540E+01	0.2021E-02	0.4897E+07	0.4213E+07	0.5195E+07
0.2355E-02	0.5845E+04	0.3822E+01	0.2205E-02	0.5256E+07	0.4520E+07	0.5576E+07
0.2405E-02	0.6272E+04	0.4125E+01	0.2404E-02	0.5640E+07	0.4850E+07	0.5983E+07
0.2455E-02	0.6728E+04	0.4450E+01	0.2618E-02	0.6051E+07	0.5203E+07	0.6419E+07
0.2505E-02	0.7217E+04	0.4798E+01	0.2849E-02	0.6492E+07	0.5581E+07	0.6887E+07
0.2555E-02	0.7740E+04	0.5172E+01	0.3098E-02	0.6963E+07	0.5985E+07	0.7387E+07
0.2605E-02	0.8300E+04	0.5573E+01	0.3367E-02	0.7469E+07	0.6418E+07	0.7923E+07
0.2655E-02	0.8899E+04	0.6003E+01	0.3656E-02	0.8010E+07	0.6882E+07	0.8497E+07
0.2705E-02	0.9540E+04	0.6463E+01	0.3968E-02	0.8589E+07	0.7377E+07	0.9111E+07
0.2755E-02	0.1023E+05	0.6957E+01	0.4303E-02	0.9208E+07	0.7908E+07	0.9769E+07
0.2805E-02	0.1096E+05	0.7487E+01	0.4664E-02	0.9871E+07	0.8475E+07	0.1047E+08
0.2855E-02	0.1174E+05	0.8054E+01	0.5052E-02	0.1058E+08	0.9082E+07	0.1122E+08
0.2905E-02	0.1258E+05	0.8662E+01	0.5470E-02	0.1134E+08	0.9731E+07	0.1203E+08
0.2955E-02	0.1348E+05	0.9314E+01	0.5919E-02	0.1215E+08	0.1042E+08	0.1289E+08
0.3005E-02	0.1444E+05	0.1001E+02	0.6402E-02	0.1302E+08	0.1116E+08	0.1381E+08
0.3055E-02	0.1546E+05	0.1076E+02	0.6921E-02	0.1395E+08	0.1196E+08	0.1480E+08
0.3105E-02	0.1655E+05	0.1156E+02	0.7479E-02	0.1494E+08	0.1280E+08	0.1585E+08
0.3155E-02	0.1772E+05	0.1242E+02	0.8078E-02	0.1600E+08	0.1370E+08	0.1697E+08
0.3205E-02	0.1896E+05	0.1333E+02	0.8721E-02	0.1713E+08	0.1466E+08	0.1817E+08
0.3255E-02	0.2029E+05	0.1431E+02	0.9412E-02	0.1833E+08	0.1569E+08	0.1945E+08
0.3305E-02	0.2170E+05	0.1536E+02	0.1015E-01	0.1962E+08	0.1678E+08	0.2081E+08
0.3355E-02	0.2321E+05	0.1648E+02	0.1095E-01	0.2099E+08	0.1795E+08	0.2227E+08
0.3405E-02	0.2481E+05	0.1768E+02	0.1180E-01	0.2246E+08	0.1919E+08	0.2382E+08
0.3455E-02	0.2652E+05	0.1897E+02	0.1272E-01	0.2402E+08	0.2051E+08	0.2548E+08
0.3505E-02	0.2834E+05	0.2034E+02	0.1370E-01	0.2568E+08	0.2191E+08	0.2724E+08
0.3555E-02	0.3027E+05	0.2180E+02	0.1476E-01	0.2744E+08	0.2340E+08	0.2911E+08
0.3605E-02	0.3231E+05	0.2337E+02	0.1588E-01	0.2932E+08	0.2499E+08	0.3111E+08
0.3655E-02	0.3449E+05	0.2504E+02	0.1709E-01	0.3132E+08	0.2667E+08	0.3323E+08
0.3705E-02	0.3680E+05	0.2682E+02	0.1839E-01	0.3344E+08	0.2845E+08	0.3548E+08
0.3755E-02	0.3924E+05	0.2872E+02	0.1978E-01	0.3569E+08	0.3035E+08	0.3787E+08
0.3805E-02	0.4183E+05	0.3074E+02	0.2126E-01	0.3808E+08	0.3235E+08	0.4040E+08
0.3855E-02	0.4457E+05	0.3290E+02	0.2285E-01	0.4061E+08	0.3446E+08	0.4309E+08
0.3905E-02	0.4746E+05	0.3520E+02	0.2456E-01	0.4329E+08	0.3670E+08	0.4593E+08
0.3955E-02	0.5051E+05	0.3765E+02	0.2638E-01	0.4613E+08	0.3906E+08	0.4894E+08
0.4005E-02	0.5373E+05	0.4026E+02	0.2832E-01	0.4912E+08	0.4155E+08	0.5212E+08
0.4055E-02	0.5712E+05	0.4303E+02	0.3041E-01	0.5228E+08	0.4417E+08	0.5548E+08
0.4105E-02	0.6068E+05	0.4597E+02	0.3263E-01	0.5562E+08	0.4693E+08	0.5902E+08
0.4155E-02	0.6443E+05	0.4910E+02	0.3501E-01	0.5913E+08	0.4982E+08	0.6275E+08
0.4205E-02	0.6836E+05	0.5242E+02	0.3754E-01	0.6282E+08	0.5286E+08	0.6668E+08
0.4255E-02	0.7247E+05	0.5594E+02	0.4025E-01	0.6670E+08	0.5604E+08	0.7080E+08

0.4305E-02	0.7678E+05	0.5967E+02	0.4314E-01	0.7077E+08	0.5937E+08	0.7513E+08
0.4355E-02	0.8127E+05	0.6362E+02	0.4622E-01	0.7504E+08	0.6285E+08	0.7966E+08
0.4405E-02	0.8596E+05	0.6780E+02	0.4951E-01	0.7950E+08	0.6647E+08	0.8440E+08
0.4455E-02	0.9083E+05	0.7222E+02	0.5301E-01	0.8415E+08	0.7024E+08	0.8936E+08
0.4505E-02	0.9589E+05	0.7689E+02	0.5673E-01	0.8901E+08	0.7415E+08	0.9453E+08
0.4555E-02	0.1011E+06	0.8181E+02	0.6070E-01	0.9406E+08	0.7821E+08	0.9991E+08
0.4605E-02	0.1066E+06	0.8700E+02	0.6492E-01	0.9930E+08	0.8241E+08	0.1055E+09
0.4655E-02	0.1122E+06	0.9247E+02	0.6940E-01	0.1047E+09	0.8675E+08	0.1113E+09
0.4705E-02	0.1180E+06	0.9822E+02	0.7417E-01	0.1104E+09	0.9121E+08	0.1173E+09
0.4755E-02	0.1239E+06	0.1043E+03	0.7923E-01	0.1162E+09	0.9581E+08	0.1235E+09
0.4805E-02	0.1300E+06	0.1106E+03	0.8460E-01	0.1221E+09	0.1005E+09	0.1299E+09
0.4855E-02	0.1362E+06	0.1173E+03	0.9030E-01	0.1283E+09	0.1053E+09	0.1365E+09
0.4905E-02	0.1426E+06	0.1242E+03	0.9633E-01	0.1346E+09	0.1102E+09	0.1432E+09
0.4955E-02	0.1490E+06	0.1315E+03	0.1027E+00	0.1410E+09	0.1152E+09	0.1501E+09
0.5005E-02	0.1556E+06	0.1391E+03	0.1095E+00	0.1476E+09	0.1203E+09	0.1572E+09
0.5050E-02	0.1616E+06	0.1463E+03	0.1159E+00	0.1536E+09	0.1249E+09	0.1637E+09
0.5100E-02	0.1683E+06	0.1545E+03	0.1234E+00	0.1604E+09	0.1301E+09	0.1709E+09
0.5150E-02	0.1750E+06	0.1631E+03	0.1314E+00	0.1672E+09	0.1353E+09	0.1783E+09
0.5200E-02	0.1818E+06	0.1720E+03	0.1397E+00	0.1741E+09	0.1406E+09	0.1858E+09
0.5250E-02	0.1886E+06	0.1813E+03	0.1486E+00	0.1811E+09	0.1458E+09	0.1933E+09
0.5300E-02	0.1953E+06	0.1909E+03	0.1579E+00	0.1880E+09	0.1510E+09	0.2009E+09
0.5350E-02	0.2020E+06	0.2008E+03	0.1677E+00	0.1950E+09	0.1562E+09	0.2085E+09
0.5400E-02	0.2087E+06	0.2111E+03	0.1780E+00	0.2019E+09	0.1614E+09	0.2161E+09
0.5450E-02	0.2153E+06	0.2217E+03	0.1888E+00	0.2088E+09	0.1665E+09	0.2236E+09
0.5500E-02	0.2218E+06	0.2326E+03	0.2001E+00	0.2156E+09	0.1715E+09	0.2311E+09
0.5550E-02	0.2281E+06	0.2439E+03	0.2121E+00	0.2223E+09	0.1764E+09	0.2385E+09
0.5600E-02	0.2343E+06	0.2554E+03	0.2245E+00	0.2289E+09	0.1812E+09	0.2457E+09
0.5650E-02	0.2404E+06	0.2673E+03	0.2376E+00	0.2353E+09	0.1859E+09	0.2529E+09
0.5700E-02	0.2462E+06	0.2794E+03	0.2513E+00	0.2416E+09	0.1904E+09	0.2599E+09
0.5750E-02	0.2519E+06	0.2919E+03	0.2655E+00	0.2477E+09	0.1948E+09	0.2667E+09
0.5800E-02	0.2573E+06	0.3046E+03	0.2805E+00	0.2535E+09	0.1990E+09	0.2733E+09
0.5850E-02	0.2626E+06	0.3176E+03	0.2960E+00	0.2592E+09	0.2030E+09	0.2798E+09
0.5900E-02	0.2675E+06	0.3309E+03	0.3122E+00	0.2646E+09	0.2069E+09	0.2859E+09
0.5950E-02	0.2723E+06	0.3444E+03	0.3291E+00	0.2698E+09	0.2105E+09	0.2918E+09
0.6000E-02	0.2767E+06	0.3581E+03	0.3467E+00	0.2747E+09	0.2140E+09	0.2975E+09
0.6050E-02	0.2809E+06	0.3720E+03	0.3649E+00	0.2793E+09	0.2172E+09	0.3028E+09
0.6100E-02	0.2848E+06	0.3862E+03	0.3839E+00	0.2836E+09	0.2203E+09	0.3079E+09
0.6150E-02	0.2885E+06	0.4005E+03	0.4035E+00	0.2877E+09	0.2231E+09	0.3127E+09
0.6200E-02	0.2918E+06	0.4150E+03	0.4239E+00	0.2914E+09	0.2257E+09	0.3171E+09
0.6250E-02	0.2949E+06	0.4297E+03	0.4451E+00	0.2949E+09	0.2281E+09	0.3212E+09
0.6300E-02	0.2977E+06	0.4445E+03	0.4669E+00	0.2980E+09	0.2302E+09	0.3250E+09
0.6350E-02	0.3002E+06	0.4595E+03	0.4895E+00	0.3008E+09	0.2321E+09	0.3285E+09
0.6400E-02	0.3024E+06	0.4745E+03	0.5129E+00	0.3034E+09	0.2339E+09	0.3317E+09
0.6450E-02	0.3044E+06	0.4897E+03	0.5370E+00	0.3056E+09	0.2354E+09	0.3345E+09
0.6500E-02	0.3061E+06	0.5050E+03	0.5618E+00	0.3076E+09	0.2367E+09	0.3370E+09
0.6550E-02	0.3075E+06	0.5203E+03	0.5875E+00	0.3092E+09	0.2378E+09	0.3392E+09
0.6600E-02	0.3086E+06	0.5357E+03	0.6139E+00	0.3106E+09	0.2387E+09	0.3411E+09
0.6650E-02	0.3095E+06	0.5512E+03	0.6410E+00	0.3117E+09	0.2394E+09	0.3427E+09
0.6700E-02	0.3102E+06	0.5667E+03	0.6690E+00	0.3125E+09	0.2399E+09	0.3440E+09
0.6750E-02	0.3106E+06	0.5822E+03	0.6977E+00	0.3131E+09	0.2402E+09	0.3450E+09
0.6800E-02	0.3108E+06	0.5977E+03	0.7272E+00	0.3135E+09	0.2404E+09	0.3457E+09
0.6850E-02	0.3108E+06	0.6133E+03	0.7575E+00	0.3136E+09	0.2404E+09	0.3462E+09
0.6900E-02	0.3106E+06	0.6288E+03	0.7885E+00	0.3135E+09	0.2402E+09	0.3464E+09
0.6950E-02	0.3102E+06	0.6443E+03	0.8204E+00	0.3132E+09	0.2399E+09	0.3463E+09
0.7000E-02	0.3096E+06	0.6598E+03	0.8530E+00	0.3127E+09	0.2395E+09	0.3460E+09

0.7050E-02	0.3089E+06	0.6753E+03	0.8863E+00	0.3120E+09	0.2389E+09	0.3455E+09
0.7100E-02	0.3080E+06	0.6907E+03	0.9205E+00	0.3111E+09	0.2382E+09	0.3448E+09
0.7150E-02	0.3069E+06	0.7061E+03	0.9554E+00	0.3101E+09	0.2373E+09	0.3439E+09
0.7200E-02	0.3057E+06	0.7214E+03	0.9911E+00	0.3089E+09	0.2364E+09	0.3429E+09
0.7250E-02	0.3043E+06	0.7367E+03	0.1028E+01	0.3075E+09	0.2353E+09	0.3416E+09
0.7300E-02	0.3029E+06	0.7518E+03	0.1065E+01	0.3060E+09	0.2342E+09	0.3402E+09
0.7350E-02	0.3013E+06	0.7669E+03	0.1103E+01	0.3045E+09	0.2330E+09	0.3386E+09
0.7400E-02	0.2996E+06	0.7820E+03	0.1141E+01	0.3027E+09	0.2317E+09	0.3369E+09
0.7450E-02	0.2978E+06	0.7969E+03	0.1181E+01	0.3009E+09	0.2303E+09	0.3351E+09
0.7500E-02	0.2959E+06	0.8117E+03	0.1221E+01	0.2990E+09	0.2288E+09	0.3331E+09
0.7550E-02	0.2939E+06	0.8265E+03	0.1262E+01	0.2970E+09	0.2273E+09	0.3310E+09
0.7600E-02	0.2919E+06	0.8411E+03	0.1304E+01	0.2950E+09	0.2257E+09	0.3289E+09
0.7650E-02	0.2898E+06	0.8557E+03	0.1346E+01	0.2928E+09	0.2241E+09	0.3266E+09
0.7700E-02	0.2876E+06	0.8701E+03	0.1389E+01	0.2906E+09	0.2224E+09	0.3243E+09
0.7750E-02	0.2854E+06	0.8844E+03	0.1433E+01	0.2884E+09	0.2207E+09	0.3219E+09
0.7800E-02	0.2831E+06	0.8986E+03	0.1478E+01	0.2860E+09	0.2189E+09	0.3194E+09
0.7850E-02	0.2808E+06	0.9127E+03	0.1523E+01	0.2837E+09	0.2172E+09	0.3169E+09
0.7900E-02	0.2785E+06	0.9267E+03	0.1569E+01	0.2813E+09	0.2153E+09	0.3143E+09
0.7950E-02	0.2761E+06	0.9406E+03	0.1616E+01	0.2789E+09	0.2135E+09	0.3117E+09
0.8000E-02	0.2737E+06	0.9543E+03	0.1663E+01	0.2764E+09	0.2117E+09	0.3090E+09
0.8050E-02	0.2713E+06	0.9680E+03	0.1711E+01	0.2740E+09	0.2098E+09	0.3063E+09
0.8100E-02	0.2688E+06	0.9815E+03	0.1760E+01	0.2715E+09	0.2079E+09	0.3036E+09
0.8150E-02	0.2664E+06	0.9948E+03	0.1809E+01	0.2690E+09	0.2060E+09	0.3009E+09
0.8200E-02	0.2639E+06	0.1008E+04	0.1859E+01	0.2664E+09	0.2041E+09	0.2981E+09
0.8250E-02	0.2614E+06	0.1021E+04	0.1910E+01	0.2639E+09	0.2022E+09	0.2954E+09
0.8300E-02	0.2590E+06	0.1034E+04	0.1962E+01	0.2614E+09	0.2003E+09	0.2926E+09
0.8350E-02	0.2563E+06	0.1047E+04	0.2014E+01	0.2586E+09	0.1982E+09	0.2895E+09
0.8400E-02	0.2527E+06	0.1060E+04	0.2066E+01	0.2551E+09	0.1954E+09	0.2856E+09
0.8450E-02	0.2488E+06	0.1072E+04	0.2120E+01	0.2511E+09	0.1924E+09	0.2812E+09
0.8500E-02	0.2447E+06	0.1085E+04	0.2173E+01	0.2470E+09	0.1892E+09	0.2766E+09
0.8550E-02	0.2404E+06	0.1097E+04	0.2228E+01	0.2426E+09	0.1859E+09	0.2718E+09
0.8600E-02	0.2361E+06	0.1109E+04	0.2283E+01	0.2382E+09	0.1825E+09	0.2669E+09
0.8650E-02	0.2316E+06	0.1120E+04	0.2339E+01	0.2337E+09	0.1791E+09	0.2619E+09
0.8700E-02	0.2271E+06	0.1132E+04	0.2395E+01	0.2292E+09	0.1756E+09	0.2568E+09
0.8750E-02	0.2226E+06	0.1143E+04	0.2452E+01	0.2246E+09	0.1722E+09	0.2518E+09
0.8800E-02	0.2181E+06	0.1154E+04	0.2509E+01	0.2201E+09	0.1687E+09	0.2467E+09
0.8850E-02	0.2137E+06	0.1165E+04	0.2567E+01	0.2156E+09	0.1652E+09	0.2417E+09
0.8900E-02	0.2093E+06	0.1176E+04	0.2626E+01	0.2111E+09	0.1618E+09	0.2367E+09
0.8950E-02	0.2049E+06	0.1186E+04	0.2685E+01	0.2067E+09	0.1585E+09	0.2318E+09
0.9005E-02	0.2002E+06	0.1197E+04	0.2751E+01	0.2019E+09	0.1548E+09	0.2265E+09
0.9055E-02	0.1959E+06	0.1207E+04	0.2811E+01	0.1976E+09	0.1515E+09	0.2217E+09
0.9105E-02	0.1918E+06	0.1217E+04	0.2871E+01	0.1934E+09	0.1483E+09	0.2170E+09
0.9155E-02	0.1877E+06	0.1226E+04	0.2932E+01	0.1893E+09	0.1451E+09	0.2124E+09
0.9205E-02	0.1837E+06	0.1235E+04	0.2994E+01	0.1853E+09	0.1421E+09	0.2078E+09
0.9255E-02	0.1798E+06	0.1245E+04	0.3056E+01	0.1813E+09	0.1390E+09	0.2034E+09
0.9305E-02	0.1760E+06	0.1253E+04	0.3118E+01	0.1774E+09	0.1361E+09	0.1991E+09
0.9355E-02	0.1722E+06	0.1262E+04	0.3181E+01	0.1737E+09	0.1332E+09	0.1949E+09
0.9405E-02	0.1686E+06	0.1271E+04	0.3245E+01	0.1700E+09	0.1304E+09	0.1908E+09
0.9455E-02	0.1651E+06	0.1279E+04	0.3308E+01	0.1665E+09	0.1277E+09	0.1868E+09
0.9505E-02	0.1617E+06	0.1287E+04	0.3372E+01	0.1630E+09	0.1250E+09	0.1829E+09
0.9555E-02	0.1583E+06	0.1295E+04	0.3437E+01	0.1596E+09	0.1224E+09	0.1792E+09
0.9605E-02	0.1551E+06	0.1303E+04	0.3502E+01	0.1563E+09	0.1199E+09	0.1755E+09
0.9655E-02	0.1519E+06	0.1311E+04	0.3567E+01	0.1531E+09	0.1175E+09	0.1719E+09
0.9705E-02	0.1488E+06	0.1318E+04	0.3633E+01	0.1500E+09	0.1151E+09	0.1684E+09
0.9755E-02	0.1458E+06	0.1326E+04	0.3699E+01	0.1470E+09	0.1128E+09	0.1650E+09

0.9805E-02	0.1429E+06	0.1333E+04	0.3766E+01	0.1441E+09	0.1105E+09	0.1617E+09
0.9855E-02	0.1401E+06	0.1340E+04	0.3832E+01	0.1412E+09	0.1083E+09	0.1585E+09
0.9905E-02	0.1373E+06	0.1347E+04	0.3900E+01	0.1384E+09	0.1062E+09	0.1554E+09
0.9955E-02	0.1346E+06	0.1354E+04	0.3967E+01	0.1357E+09	0.1041E+09	0.1523E+09
0.1000E-01	0.1320E+06	0.1360E+04	0.4035E+01	0.1331E+09	0.1021E+09	0.1494E+09
0.1005E-01	0.1295E+06	0.1367E+04	0.4103E+01	0.1305E+09	0.1001E+09	0.1465E+09
0.1010E-01	0.1270E+06	0.1373E+04	0.4172E+01	0.1280E+09	0.9821E+08	0.1437E+09
0.1015E-01	0.1246E+06	0.1379E+04	0.4240E+01	0.1256E+09	0.9635E+08	0.1409E+09
0.1020E-01	0.1222E+06	0.1386E+04	0.4309E+01	0.1232E+09	0.9453E+08	0.1383E+09
0.1025E-01	0.1200E+06	0.1392E+04	0.4379E+01	0.1209E+09	0.9277E+08	0.1357E+09
0.1030E-01	0.1177E+06	0.1398E+04	0.4449E+01	0.1186E+09	0.9105E+08	0.1332E+09
0.1035E-01	0.1156E+06	0.1403E+04	0.4519E+01	0.1165E+09	0.8937E+08	0.1307E+09

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 deltat t  0.103950E-01 intg t  0.103948E-01
PMAXMEAN Pa    0.313603E+09 time at PMAXMEAN sec    0.685009E-02
PMAXBASE Pa    0.240397E+09 time at PMAXBASE sec    0.682509E-02
PMAXBREECH Pa    0.346365E+09 time at PMAXBREECH sec    0.691510E-02
muzzle VELOCITY m/s    0.140782E+04 time of muzzle velocity sec    0.103927E-01
total initial energy available J =    0.437119E+08
FOR PROPELLANT  1 MASSFRACT BURNT IS    0.997470E+00
total energy remaining in gas J=    0.295069E+08
energy loss from projectile translation J=    0.971088E+07
energy loss from projectile rotation J=    0.000000E+00
energy lost to gas and propellant motion J=    0.292176E+07
energy lost to bore resistance J=    0.000000E+00
energy lost to recoil J=    0.182576E-11
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